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The IJC Menomonee River Watershed Study Simulation of Pollutant Loadings and Runoff Quality. Volume 5

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Volume 5

The IJC Menomonee River Watershed Study

Simulation of Pollutant Loadings And Runoff Quality

Menomonee River ★

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FOREWORD

The Environmental Protection Agency was established to coordinate administration of the major Federal programs designed to protect the quality of our environment.

An important part of the Agency's effort involves the search for information about environmental problems, management techniques, and new technologies through which optimum use of the nation's land and water resources can be assured and the threat pollution poses to the welfare of the American people can be minimized.

The Great Lakes National Program Office (GLNPO) of the U.S. EPA, was established in Region V, Chicago to provide a specific focus on the water quality concerns of the Great Lakes. GLNPO also provides funding and personnel support to the International Joint Commission activities under the U.S.- Canada Great Lakes Water Quality Agreement.

Several land use water quality studies have been funded to support the pollution from Land Use Activities Reference Group (PLUARG) under the Agreement to address specific objectives related to land use pollution to the Great Lakes. This report describes some of the work supported by this Office to carry out PLUARG study objectives.

We hope that the information and data contained herein will help planners and managers of pollution control agencies make better decisions for carrying forward their pollution control responsibilities.

Madonna F. McGrath
Director
Great Lakes National Program Office

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Simulations of sediment loadings for various land uses in 48 subwatersheds of the Menomonee River Watershed are preformed using the LANDRUN model. In order to determine ratios estimated for pervious areas in each subwatershed.

The Model Enhanced Unit Loading (MEUL) method utilizing the LANDRUN model has been developed to simulate potential pollutant loadings from urban and non-urban land uses.

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PREFACE

Prediction of pollutant loadings from non-point sources is an important aspect of water quality management. A well-calibrated mathematical model verified with extensive monitoring data may be applied to other watersheds for predictive purposes. This volume contains two reports on the application of the LANDRUN model and a discussion of a simple, empirical model for predicting runoff quality. The LANDRUN model is utilized to 1. assess sediment loadings from 48 subwatersheds in the Menomonee River Watershed in an attempt to identify critical areas that are most cost-effective in terms of pollution control and 2. obtain unit pollutant loadings for typical land uses to better understand the processes involved in pollution generation and transport from urban and non-urban areas.

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*Detailed contents are presented at the beginning of each part.

PART I

ASSESSING POLLUTANT LOADINGS FROM SUBWATERSHEDS WITH MIXED LAND USES

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ABSTRACT

Simulations of sediment loadings for various land uses in 48 subwatersheds of the Menomonee River Watershed are performed using the LANDRUN model. In order to determine critical source areas, simulated loadings are adjusted based on delivery ratios estimated for pervious areas in each subwatershed. Nine subwatersheds, consisting of 16% of the total area of the Watershed, are identified as critical source areas with developing lands being the primary contributors of sediments. The criticality of a subwatershed in terms of nonpoint source pollution appears to be enhanced by the extent of connected imperviousness and proximity to the stream of that area.

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I-1. INTRODUCTION

Identifying critical source areas of nonpoint pollution in a watershed is imperative if economical means of remedial control measures are to be adopted. Because monitoring of all potential source areas in relatively large watersheds, like the Menomonee River Watershed (35,000 ha), incurs extremely large expense and time, a model capable of predicting pollutant loads from smaller components of the total watershed is very useful.

LANDRUN, a dynamic runoff-sediment overland transport model, after initial calibration and verification, has demonstrated its capability of simulating field data for such parameters as runoff, sediment and adsorbed phosphorus (1). One application of LANDRUN is the prediction of pollutant loadings from subwatersheds of diverse land uses and physical characteristics. An attempt was made to use LANDRUN in simulating runoff and sediment loadings from 48 subwatersheds in the Menomonee River Watershed. Such application of the model is described in this report and results obtained should aid in demonstrating what land features, land uses or land activities contribute to high pollutant loadings. Water and sediment loadings were simulated during the summer of 1977.

I-2. CONCLUSIONS

The LANDRUN model was capable of simulating water and sediment loadings for various land uses in 48 subwatersheds. Delivery ratio for each land use was necessary to adjust sediment loadings from pervious areas. Simulated sediment loadings were found to compare reasonably well with monitored data from the mainstem stations.

Nine critical nonpoint source subwatersheds, constituting 16% of the total area of the Watershed, were identified and contributed about 50% of the total sediment loadings. Developing areas were the primary contributor of sediments. Although developing lands occupy a small portion of the subwatershed (1 to 5%), they contributed high amounts (50 to 85%) of sediment loadings. The criticality of a source area can be enhanced by the extent of connected imperviousness and proximity to the stream of that subwatershed. It appears that developing areas in urbanizing subwatersheds are the most cost-effective in terms of management.

I-3. METHODOLOGY

Source and Form of Data for LANDRUN Simulation

LANDRUN is a mathematical model developed as a method of analysis for estimating the quantity and quality of runoff and eroded particulates emanating from watersheds having mixed land uses. The description of this model and the discussion of its initial calibration and verification are given in (1).

To perform LANDRUN simulations for the 48 subwatersheds in the Menomonee River Watershed (Fig. I-1.) two types of data are needed, namely, 1. land use and associated characteristics in each subwatershed and 2. meteorological informatiom obtained within and near the Watershed. Data on land use, soils, slope and degree of imperviousness on the 48 subwatersheds were provided by the Land Data Management System (Land DMS) described in (2). The 79 land use descriptions were consolidated into 14 land use categories (Table I-1). The consolidation grouped similar land uses and land uses that have similar potential for non-point pollution (3). Data obtained from the Land DMS were in the form of area of each slope category for each soil type found for each of the 14 land uses in each subwatershed. The Land DMS also provided the degree of imperviousness for each land use for each of the subwatersheds.

Meteorological data were obtained from two sources. Precipitation data, in the form of hourly precipitation totals, were furnished by the U.S. Geological Survey (USGS) from eight precipitation gauges located throughout the Watershed. Maximum and minimum daily temperatures, as well as daily evaporation values, were obtained from the National Weather Service at Mitchell Field.

Dust and dirt data which include dust and dirt fallout, washout coefficient and sweeping efficiency were obtained from the Chicago study on pollution from urban areas (4). Information on sweeping frequency was provided by the Engineering Office of the cities in the Watershed.

Manipulation of Land DMS Data Prior to Calibration

LANDRUN, like other similar overland flow models, is sensitive to the degree of imperviousness connected directly to storm sewers and streams, and for pervious areas, to soil permeability, interception and depression storage. The model requires dividing the Watershed into uniform areas based on land use and soil characteristics. A land use with two different soil groups was considered as two sub-areas. For a single land use in a subwatershed, the many soil types were grouped into hydrologic soil groups B, C and D (soils under group A are insignificant in the Watershed). An area-

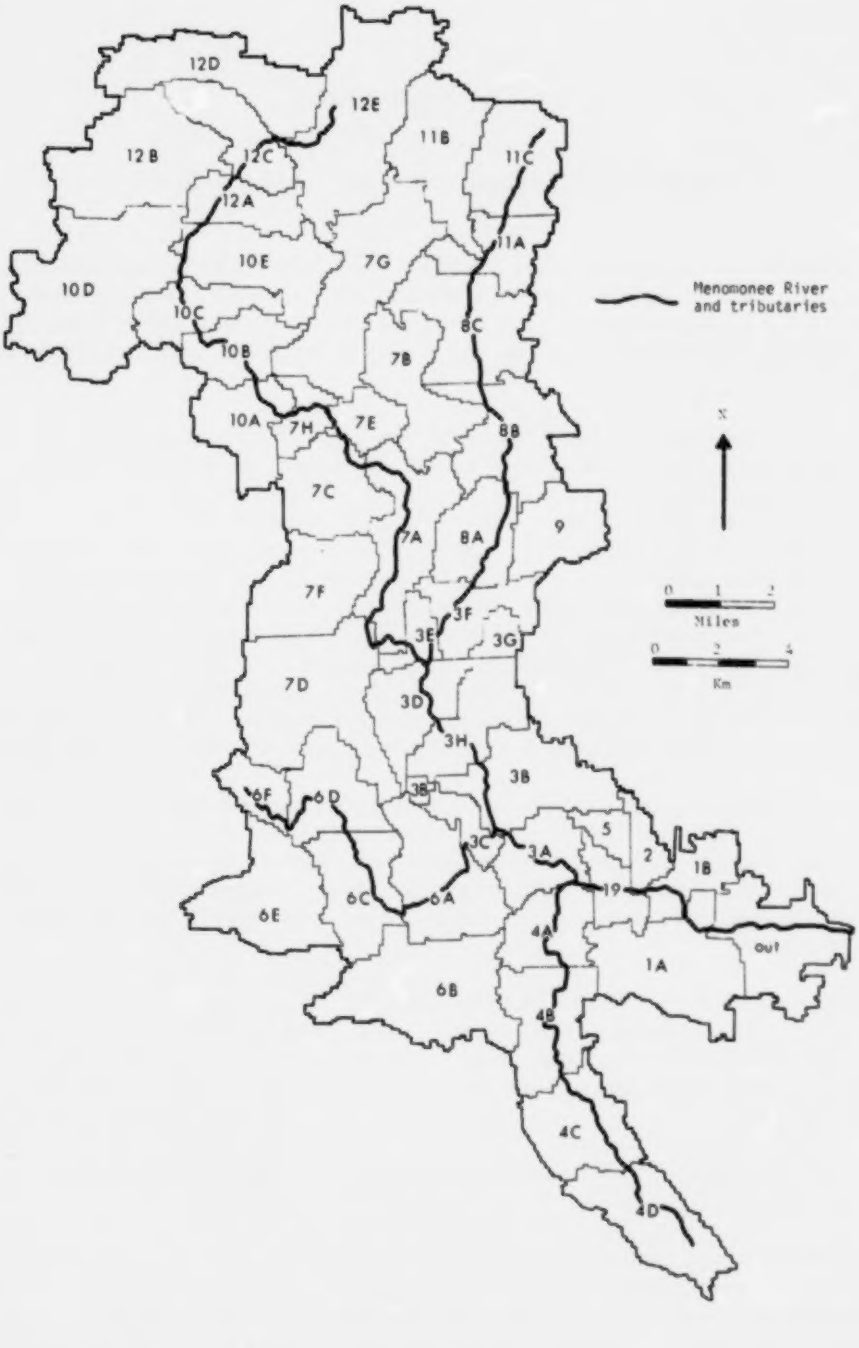
12D
12E
11B
11C
12B
12C
12A
11A
10E
7G
10D
Menomonee River and tributaries
10C
8C
10B
7B
N
10A
7H
7E
8B
7C
9
7A
8A
7F
0 1 2
Miles
0 2 4
Km
3F
3E
3G
7D
3D
3H
3B
3B
6F
6D
5
3C
3A
2
1B
19
6C
6A
6E
4A
out
1A
6B
4B
4C
4D

Fig. I-1. The 48 subwatersheds in the Menomonee River Watershed.

Table I-1. Land use categories (1975) in the 48 subwatersheds of the Menomonee River Watershed

No.	Area, ha	Land use* distribution, %														Imperviousness, %	
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	Total	Connected
12A	429	0.4	3.3	0	6.7	8.7	0.7	7.8	17	48	2.6	0.6	0	0	4.0	17	6
12B	1,200	4.3	3.2	1.9	0.3	6.2	1.6	3.6	36	29	6.0	7.0	0.5	0	0.2	7	1
12C	571	0.6	1.8	0	0	9.6	1.9	1.4	31	38	9.4	4.0	0.5	0	0.4	8	1
12D	981	0	2.4	0	0	3.5	1.5	0.3	45	32	12	3.2	0.3	0	0	2	1
12E	1,592	0	0.7	0	0	4.3	1.4	0.4	31	30	24	0.6	0.2	0	0	2	1
10A	599	0.2	4.0	0	2.0	37	0.2	4.4	1.3	25	1.3	24	0	0.2	0.6	23	12
10B	459	1.1	4.6	5.9	1.8	36	2.5	1.9	15	25	4.5	0.3	0	0	1.0	28	2
10C	502	0.1	3.1	2.7	0	9.6	1.4	1.8	31	32	13	5.3	0	0	0	7	1
10D	1,610	1.8	1.1	2.2	0.1	12	1.4	5.9	19	38	13	4.4	0.2	0	0.5	8	2
10E	853	0	0.2	0.8	0	16	1.2	1.7	37	26	0.5	11	0	0	0.1	6	2
7A	981	3.1	5.7	8.0	0	18	0.6	5.0	0.9	40	7.0	2.2	0	0	1.7	23	11
7B	820	5.9	5.9	2.7	0.4	4.8	1.3	1.5	18	51	2.8	0.8	0	7.6	0.6	11	1
7C	718	0	3.1	0	0.2	48	0.7	6.7	9.0	28	2.6	0.7	0	0	0	17	1
7D	1,406	1.1	3.2	0	0.1	56	0.4	6.5	5.1	19	3.6	5.0	0	0	0.3	18	1
7E	301	2.7	8.2	3.5	0	28	1.0	3.0	5.5	41	5.9	0	0	0	0.8	24	7
7F	832	1.1	6.6	0	0	24	0.9	4.9	21	37	3.9	0.6	0	0	0.2	12	1
7G	1,363	2.7	4.9	2.4	0.2	8.3	1.5	6.5	20	32	8.9	4.1	0.2	0	0.1	11	1
7H	251	0.2	8.3	0	4.5	65	0	4.6	0.1	16	0.4	1.3	0.1	0	0	34	17
11A	527	0	1.2	0	0	2.4	2.5	0.2	68	18	6.2	1.5	0	0	0.2	5	1
11B	852	0	0.2	0	0.2	7.6	1.4	2.7	33	38	10	4.0	0.8	0	1.5	5	2
11C	765	0	1.3	0	0	12	1.5	2.1	39	31	12	0.8	0.7	0	0	3	1
9	555	3.4	15	1.6	6.8	41	0.2	3.0	0.2	24	0.4	0.1	0	2.6	0.4	42	27
8A	599	0.1	2.0	7.7	2.9	38	0.4	4.5	2.6	40	3.1	0.6	0	0	0.5	26	10
8B	853	1.3	7.8	0	2.9	13	0.9	5.8	14	45	5.5	2.9	0	1.6	0	13	8
8C	1,011	2.2	9.8	0	1.9	4.3	1.0	6.2	26	28	13	6.9	0	0	0.4	12	1
6A	970	2.0	8.9	4.1	2.9	47	0	1.0	0	30	0.4	0	0	3.8	0.1	41	17
6B	1,523	4.5	15	5.7	2.6	41	0	2.8	0	26	0.8	1.0	0	0.3	0.6	39	12
6C	744	0.5	6.9	0	1.8	58	0.1	4.7	0	20	6.3	1.0	0	0	0.1	23	1
6D	669	5.1	1.0	0	1.3	53	0.4	4.9	0	24	4.4	6.3	0	0	0.1	14	1
6E	974	0	8.3	0	0	45	0.3	5.8	3.0	26	7.4	4.5	0	0	0.2	21	1
6F	294	0.3	4.3	0	0	25	0.3	0.1	0	50	10	10	0	0	0	10	1
4A	545	4.0	11	7.0	5.4	47	0	0.2	0	26	0	0	0	0	0	51	33
4B	752	2.5	9.1	0.4	2.3	69	0	0.4	0	16	0	0	0	0	0.3	48	30
4C	707	0.1	5.5	0	11	67	0	2.5	0	13	0	0	0	0	0.1	52	32
4D	799	0	6.4	2.7	5.1	49	0.1	5.2	1.9	25	1.7	1.1	0	1.6	0.1	32	20
3A	527	0.2	5.8	0	4.1	42	0	0.1	1.5	43	2.1	0	0	0	1.7	46	32
3B	940	1.3	4.5	0.2	5.0	69	0	0.3	0	19	0	0	0	0	0.7	51	30
3C	225	0	20	4.7	8.4	23	0	0.8	0	39	2.5	0	0	0	1.0	47	33
3D	605	15	24	2.1	0.5	26	0	1.4	0	30	1.1	0	0	0.1	0.6	51	18
3E	230	7.9	36	7.9	3.7	11	0	0.4	0	33	0.3	0	0	0.6	1.3	40	36
3F	406	3.0	17	1.9	9.1	32	0.1	2.4	0.6	33	0	0	0	0	0.6	46	30
3G	151	0.2	85	0	4.4	8.6	0	0	0	1.5	0	0	0	0	0	21	11
3H	662	8.1	15	1.2	4.4	32	0	1.8	0	37	0	0	0	0	0.7	47	30
5	175	0	5.6	0	0.4	87	0	2.0	0	5.3	0	0	0	0	0	55	33
2	132	0	7.2	0	3.3	77	0	0.2	0	13	0	0	0	0	0	56	34
1A	1,143	17	25	3.8	2.3	33	0.1	0	0	18	0	0	0	0	0.6	73	50
1B	309	8.3	18	5.9	5.5	40	0	0.2	0	18	0	0	0	3.2	0.7	58	41
1C	305	5.0	12	0	2.5	65	0	1.1	0	13	0	0	0	0.4	0.8	50	38
Total	34,397	2.6	7.3	1.8	1.9	29	0.7	3.1	16	29	5.7	3.1	0.1	0.3	0.4	26	11

*Land use categories are: 1-industrial, 2-commercial, 3-freeway (other roads are proportionately distributed among the other land uses), 4-high density residential, 5-medium density residential, 6-low density residential, 7-land under development, 8-row crops, 9-pasture and small grains, 10-forested land and woodlots, 11-wetlands, 12-feedlots, 13-landfill and dumps, 14-water areas (land use categories are described in Table III-5 found in (3)).

weighted mean slope was calculated for each land use-soil group sub-area (e.g., the row crop land use in a subwatershed was computed as Row Crop B, Row Crop C and Row Crop D; and having an associated area and mean slope). Saturation permeability and other soil characteristics could be inputted for each of the 3 soil groups within a particular land use.

Land DMS-land use data segregated all streets, freeways and off-street parking areas from other land uses into a transportation land use. In order to represent accurately the nature of urban land uses, it was necessary to integrate these impervious areas back into the various land uses. Total area and degree of imperviousness data were adjusted to account for this additional area. Freeways were retained as a separate land use.

Calibration, Verification and Determination of Degree of Connected Imperviousness

Starting with values used in the initial calibration and verification of the model (5), individual events, sequences of events and eventually the entire 1977 summer season were simulated for subwatersheds in which good monitored data were available for comparison.

The hydrology portion of the model was first calibrated on subwatersheds 5 and 9 (Schoonmaker Creek-413010 and Noyes Creek-413011), each of which had water quality data and flow information from a sampling site which monitored only that subwatershed. Both subwatersheds are predominantly medium density residential although the Noyes Creek area is a newer development. Additional calibration was performed on the 3 subwatersheds (11A, 11B and 11C) which comprise the area monitored by the Donges Bay Road station (463001) and the 4 subwatersheds (4A, 4B, 4C and 4D) monitored by the Honey Creek sampling site (413006). The Donges Bay Road subwatersheds are predominantly rural while the Honey Creek subwatersheds are mostly residential, but with significant pervious areas on the southernmost subwatershed (4D). Simulation of these urban, rural and mixed land use areas and comparisons of simulated flows with monitored flows led to the determination of connected imperviousness values for the calibration subwatersheds. Calibration of the sediment portion of the model was done on the Noyes and Schoonmaker Creeks subwatersheds as these small urban areas were expected to have a delivery ratio much closer to unity than the larger subwatersheds or rural areas.

Simulations on other subwatersheds for verification showed that the degree of connected imperviousness could be described as a function of the extent of storm sewering in a subwatershed. The degree of directly connected imperviousness is the single most important factor influencing simulated runoff from urban areas. For this reason, it was necessary to obtain detailed information from maps, conversation with city engineers, etc. concerning the extent of storm sewering, the precise location of new residential developments, the usage of grass ditches for drainage, etc. The result of this exercise was a set of connected imperviousness values for the land uses modified according to individual differences in each subwatershed. The area of directly connected impervious surfaces was calculated for each land use in each subwatershed in the following manner. The model was used to determine percentages of directly connected imperviousness for completely sewered and unsewered subwatersheds. Values for partially sewered subwatersheds were derived by prorating on the basis of the land use which was in the sewered area of that subwatershed. Examples of percentages of directly connected imperviousness are shown below.

Land use	Completely sewered	Partially sewered (~60%)	Unsewered
Industrial	80	45	8
Medium density residential	60	35	3
Low density residential	20	5	1
Parks/recreation	30	15	1

Simulations for 48 Subwatersheds and Determination of Sediment Delivery Ratios

After calibration and verification was completed, simulations were run on all subwatersheds. Simulated flow values from the individual subwatersheds were summed accordingly and were found to compare favorably with measured flows at the several mainstem river sampling stations. Simulated sediment values corresponded reasonably well with loading estimates calculated from monitored values for urban areas where a large part of the sediment originates from impervious surfaces and the degree of connected imperviousness is high. Calibration in these areas is accomplished by manipulation of the cropping management factor for developing areas and doubling the literature values for dust and dirt accumulation values. In more pervious areas and rural areas, simulated sediment values were much higher than monitored loading estimates (e.g., as much as 20 to 30 times higher in Donges Bay Road). Thus, there was a need to develop a series of sediment delivery ratios for the land uses in each subwatershed.

Proceeding as in the runoff calibration process, it was determined that sediment delivery ratios were dependent on the extent of storm sewering (connected imperviousness) in the subwatersheds. Other important factors are proximity to runoff channels and characteristics of the land use (e.g., parks vs. small grains, airport vs. shopping center). Again, it was necessary to collect detailed information to characterize the land uses in each watershed.

Land uses were grouped into three categories and each category was assigned a sediment delivery ratio for each subwatershed. "Urban" land uses included industrial, commercial, medium and high density residential. "Rural" land uses included agricultural areas, parks, low density residential and landfills. Developing lands (construction), the third category, had such a high sediment yield compared to the other land uses that it was assigned its own delivery ratio. Resulting delivery ratios ranged from 1.0 for "urban" land uses in completely storm sewered urban areas to 0.01 for developing lands in non-sewered areas. Table I-2 shows the sediment delivery ratios for the subwatersheds for the 1977 summer simulations.

Table I-2. Estimated sediment delivery ratios for various land uses (LU) in the 48 subwatersheds of the Menomonee River Watershed

Monitoring station		Adjacent subwatershed	Delivery ratios*		
STORET No.	Location		LU 1-5	LU 7	LU 6,8-13
673001	MR at River Lane Rd. (Hwy. F)	12A,12E	0.34	0.02	0.03
		12B,12C,12D	0.03	0.015	0.03
683002	MR at Pilgrim Rd. (Hwy. YY)	10A	0.80	0.02	0.03
		10B,10C,10D	0.03	0.015	0.03
		10E	0.40	0.02	0.03
683001	MR at 124th St. (Hwy. M)	7A	1.0	0.30	0.06
		7B,7D,7F,7G	0.03	0.03	0.03
		7C	0.15	0.04	0.03
		7E	0.53	0.13	0.03
		7H	0.81	0.30	0.06
463001	Donges Bay Rd., Mequon	11A,11B,11C	0.03	0.03	0.03
413011	Noyes Creek at 91st St.	9	1.0	0.70	0.06
413008	Little MR at Appleton Ave. (Hwy. 175)	8A	1.0	0.40	0.06
		8B	1.0	0.10	0.03
		8C	0.03	0.07	0.03
413007	Underwood Creek above Hwy. 45 off North Ave.	6A	0.35	0.10	0.10
		6B	0.25	0.04	0.05
		6C,6D,6F	0.03	0.015	0.03
		6E	0.03	0.01	0.03
413006	Honey Creek 140 m above confluence with MR	4A,4B,4C	1.0	0.70	0.30
		4D	1.0	0.50	0.30
413005	MR at 70th St. Bridge	3A,3B,3C,3E,3F,3H	1.0	0.70	0.30
		3D	0.52	0.30	0.10
		3G	0.60	0.70	0.15
413010	Schoonmaker Creek at Vliet St.	5	1.0	0.70	0.30
413009	MR at Hawley Rd.	2	1.0	0.70	0.30
413004	MR above 27th St. at Falk Corp.	1A,1B,1C	1.0	1.0	1.0

*For pervious areas only; delivery of dust and dirt from impervious areas is assumed to be 1.0.

I-4. RESULTS AND DISCUSSION

Extensive monitoring at the mainstem of the Menomonee River reveals that the more urbanized areas in the lower portion of the Watershed contributed greater sediment loadings than the rural upper portion (Fig. I-2). Mainstem monitoring could show general areas of nonpoint sources of pollutants, however, identification of critical areas is quite difficult because adjacent areas monitored by the major stations are too large (3,000 to 7,000 ha). Estimation of pollutant loadings on smaller units should provide reasonable precision for identifying critical source areas where best management practices can be applied.

Water and sediment loadings simulated by LANDRUN during the summer of 1977 for the 48 subwatersheds (200 to 1,600 ha) of the Menomonee River Watershed are shown in Tables I-A-1 to I-A-48. Loadings are given for all land uses identified in a particular subwatershed. The sediment data were adjusted accordingly taking into account delivery ratios (Table I-2) for pervious areas in the various land uses. Dust and dirt accumulations on impervious surfaces were assumed to have 100% delivery. Delivery ratio for a land use was estimated based on its physical characteristics, extent of connected imperviousness and proximity to the stream.

Simulated sediment loadings were found to compare reasonably well with those monitored at all but one of the mainstem stations (Fig. I-2). At station 673001, the simulated data was almost 3 times as high as the monitored data. The extremely low sediment loading measured at this station could be due to the trapping effect of a large pond just upstream of the station. The close agreement between the simulated and monitored data indicates the validity of the delivery ratios used for each land use and the integrity of the sediment estimates for each subwatershed.

Results of simulations showed that nine subwatersheds (7H, 7A, 8A, 9, 3F, 3H, 3C, 4C and 4D) contributed significant amounts of sediments (Fig. I-3). These high source areas, located in the urbanized lower portion of the Watershed, constitute 16% of the total area (calculated up to station 413005) but contributed almost 50% of the total sediment loadings. The high sediment yields from these subwatersheds can be ascribed mainly to developing areas and--to a certain degree--to medium density residential areas. Developing areas were present in almost all of the subwatersheds. However, high amounts of sediments were transported from developing areas in the critical subwatersheds essentially because of their short distances to the stream and extensive connected imperviousness. Although high amounts of sediment can be eroded in other subwatersheds particularly those in the rural portion of the Watershed, delivery of sediment to the stream could be impeded as a result of low connected imperviousness and/or greater distance to the stream. Medium density residential areas, the predominant land use in the critical subwatersheds, were significant sources of sediment loadings. Due to extensive impervious surfaces in these areas, dust and dirt washoff was prevalent.

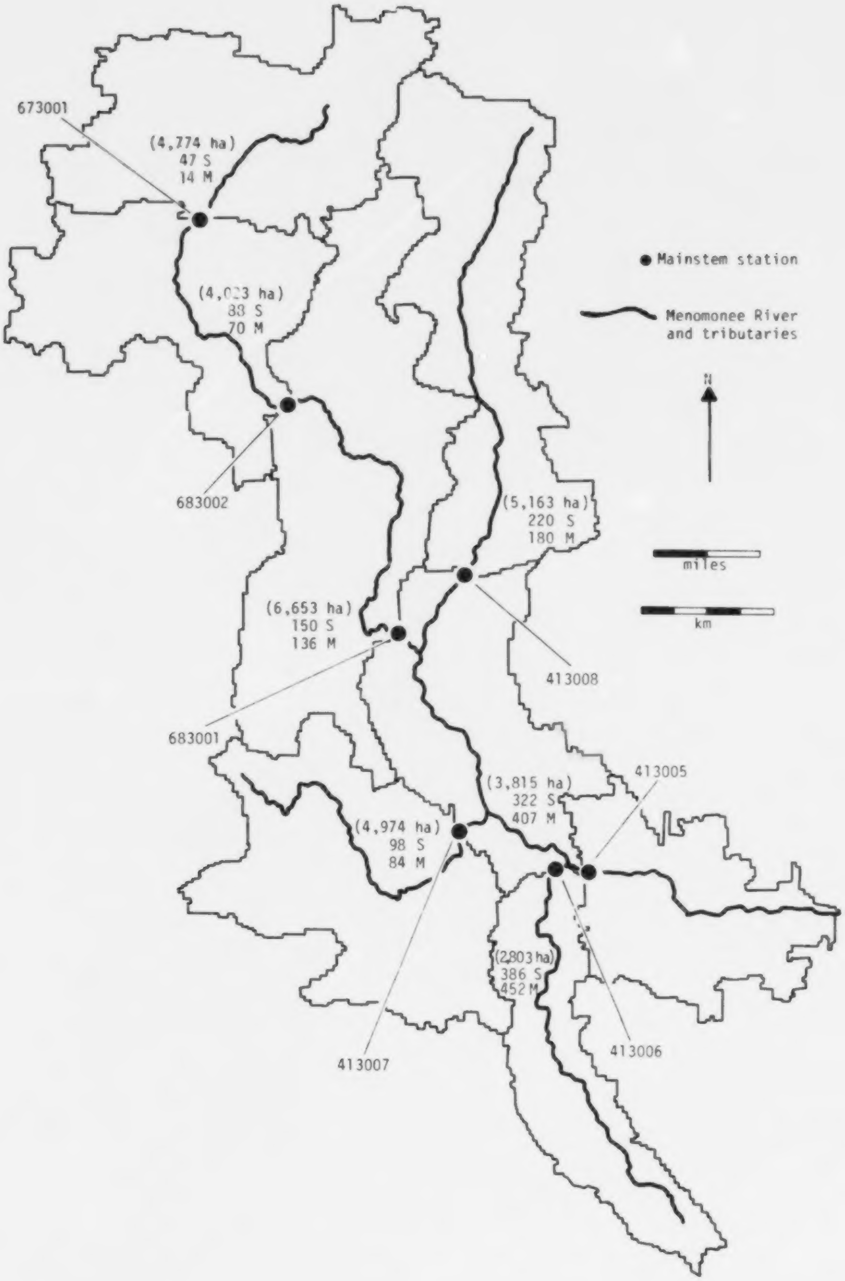
673001
(4,774 ha)
47 S
14 M
(4,023 ha)
83 S
70 M
683002
(5,163 ha)
220 S
180 M
(6,653 ha)
150 S
136 M
683001
413008
(3,815 ha)
322 S
407 M
413005
(4,974 ha)
98 S
84 M
(2,803 ha)
386 S
452 M
413007
413006
● Mainstem station
Menomonee River and tributaries
N
miles
km

Fig. I-2. Simulated (S) and monitored (M) sediment loadings (kg/ha) from area adjacent to mainstem monitoring stations--summer, 1977 (monitored data taken from (6)).

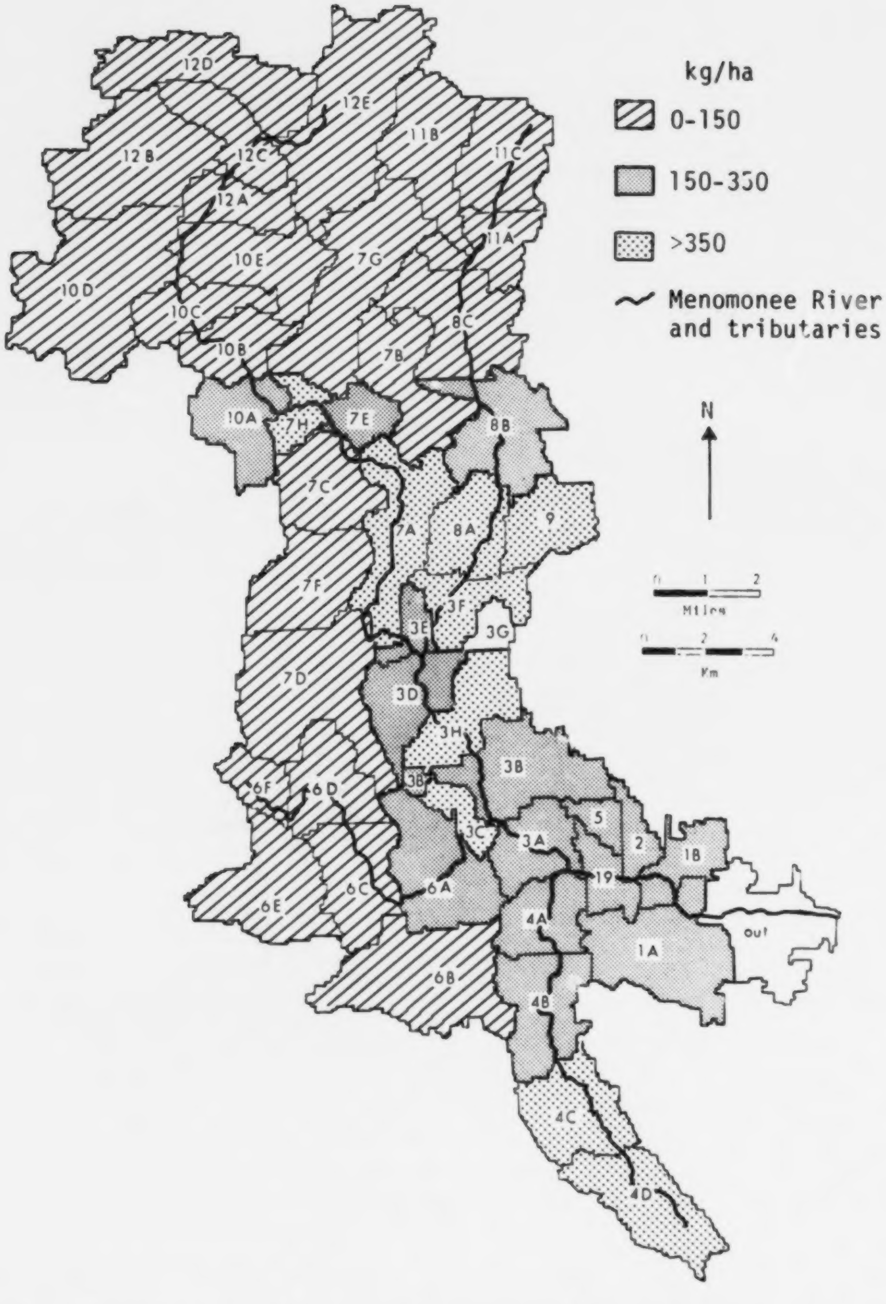
kg/ha
0-150
150-350
>350
Menomonee River and tributaries
N
0 1 2
Miles
0 2 4
Km
12D
12E
12B
12C
12A
11B
11C
11A
10E
10D
10C
10B
10A
7G
7B
7H
7E
7C
7A
7F
7D
8C
8B
8A
9
3F
3E
3G
3D
3H
3B
3B
3C
3A
5
2
1B
19
1A
out
6F
6D
6C
6E
6A
6B
4A
4B
4C
4D

Fig. I-3. Distribution of simulated sediment loadings in the Menomonee River Watershed--summer, 1977.

It is evident from the critical subwatersheds (Tables I-A-11, I-A-18, I-A-22, I-A-25, I-A-34, I-A-35, I-A-38, I-A-41 and I-A-43) that the majority of the sediment loadings (50 to 85%) originated from small areas (1 to 5%) that were under development. This also can be seen in Table I-3, which is an integration of the loadings from various land uses in the entire Watershed. Over 50% of the total sediment loadings was contributed by developing areas occupying just 3% of the total area of the Watershed.

It has been shown that the model is a useful tool in identifying critical nonpoint source areas of sediment in the Menomonee River Watershed. Results indicate that developing areas in urbanizing subwatersheds are the most cost-effective to manage. The method is applicable to other watersheds. However, the difficulty of simulating sediment loadings on pervious areas requires some recalibration and reverification of the model in other watersheds using monitored data.

Table I-3. Water (m^3) and sediment (kg) loadings estimated by LANDRUN for each land use in the Menomonee River Watershed (area in ha)--Summer 1977

LAND USE	WATER PERV	WATER IMPER	WATER TOTAL	SEDIMENT PERV	DUST/DIRT IMPER	SEDIMENT TOTAL	AREA PERV	AREA IMPER	AREA TOTAL
INDUSTRIAL	108658. 2.3%	998707. 7.6%	1107365. 6.2%	5449. .1%	117205. 7.8%	122654. 2.2%	189. .8%	449. 6.4%	638. 2.0%
COMMERCIAL	530245. 11.4%	3023765. 23.1%	3554010. 20.1%	50976. 1.3%	350339. 23.4%	401315. 7.3%	770. 3.1%	1334. 19.0%	2104. 6.5%
MED/DENS/RES	1318740. 28.4%	5813647. 44.5%	7132387. 40.2%	592661. 14.8%	662801. 44.3%	1255462. 22.8%	6039. 24.0%	3071. 43.8%	9110. 28.3%
LO/DENS/RES	32057. .7%	4453. .0%	36510. .2%	3841. .1%	475. .0%	4316. .1%	220. .9%	27. .4%	247. .8%
HI/DENS/RES	139462. 3.0%	972818. 7.4%	1112280. 6.3%	30810. .8%	110318. 7.4%	141128. 2.6%	245. 1.0%	359. 5.1%	604. 1.9%
DEVELOPING	1087328. 23.4%	258787. 2.0%	1346115. 7.6%	2802398. 69.8%	28106. 1.9%	2830504. 51.4%	801. 3.2%	272. 3.9%	1073. 3.3%
ROW CROPS	77469. 1.7%	0. .0%	77469. .4%	316601. 7.9%	0. .0%	316601. 5.7%	4806. 19.1%	0. .0%	4806. 14.9%
PK/REC/PASTR	1093929. 23.5%	677001. 5.2%	1770930. 10.0%	178430. 4.4%	78421. 5.2%	256851. 4.7%	8949. 35.5%	813. 11.6%	9762. 30.3%
FORESTS	49089. 1.1%	0. .0%	49089. .3%	4903. .1%	0. .0%	4903. .1%	1969. 7.8%	0. .0%	1969. 6.1%
WETLANDS	170156. 3.7%	0. .0%	170156. 1.0%	6695. .2%	0. .0%	6695. .1%	1069. 4.2%	0. .0%	1069. 3.3%
FEEDLOTS	16278. .4%	0. .0%	16278. .1%	19268. .5%	0. .0%	19268. .3%	32. .1%	0. .0%	32. .1%
LANDFILL	26359. .6%	0. .0%	26359. .1%	1004. .0%	0. .0%	1004. .0%	106. .4%	0. .0%	106. .3%
WATER	0. .0%	655984. 5.0%	655984. 3.7%	0. .0%	72644. 4.9%	72644. 1.3%	0. .0%	142. 2.0%	142. .4%
FREEWAYS	0. .0%	670673. 5.1%	670673. 3.8%	0. .0%	77354. 5.2%	77354. 1.4%	0. .0%	542. 7.7%	542. 1.7%
TOTALS	4649770. 100.0%	13075835. 100.0%	17725605. 100.0%	4013036. 100.0%	1497663. 100.0%	5510699. 100.0%	25196. 100.0%	7009. 100.0%	32205. 100.0%

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APPENDIX I-A. SIMULATED LOADINGS FOR 48 SUBWATERSHEDS

Table I-A-1. Water (m^3) and sediment (kg) loadings estimated by LANDRUN for each land use in Subwatershed 17A (area in ha)--Summer 1977

LAND USE	WATER PERV	WATER IMPER	WATER TOTAL	SEDIMENT PERV	DUST/DIRT IMPER	SEDIMENT TOTAL	AREA PERV	AREA IMPER	AREA TOTAL
INDUSTRIAL	275. .2%	2125. 1.7%	2400. 1.0%	32. .1%	213. 1.7%	245. .5%	0. .0%	2. 2.3%	2. .4%
COMMERCIAL	12615. 10.4%	10260. 8.1%	22875. 9.2%	1107. 2.7%	1028. 8.1%	2135. 3.9%	6. 1.7%	8. 11.4%	14. 3.3%
MED/DENS/RES	12850. 10.6%	11711. 9.2%	24561. 9.9%	2610. 6.3%	1173. 9.2%	3783. 7.0%	25. 7.1%	12. 16.2%	37. 8.7%
LO /DENS/RES	633. .5%	102. .1%	735. .3%	99. .2%	10. .1%	109. .2%	3. .7%	0. .5%	3. .7%
HI /DENS/RES	16177. 13.3%	11611. 9.2%	27788. 11.2%	1987. 4.8%	1163. 9.2%	3150. 5.8%	17. 4.7%	12. 16.1%	29. 6.7%
DEVELOPING	42940. 35.4%	3902. 3.1%	46842. 18.9%	30744. 74.3%	390. 3.1%	31134. 57.6%	25. 7.1%	8. 10.8%	33. 7.6%
ROW CROPS	534. .4%	0. .0%	534. .2%	2005. 4.8%	0. .0%	2005. 3.7%	74. 20.9%	0. .0%	74. 17.3%
PK/REC/PASTR	34318. 28.3%	2816. 2.2%	37134. 15.0%	2740. 6.6%	283. 2.2%	3023. 5.6%	192. 54.1%	14. 19.5%	207. 48.1%
FORESTS	452. .4%	0. .0%	452. .2%	22. .1%	0. .0%	22. .0%	11. 3.2%	0. .0%	11. 2.6%
WETLANDS	587. .5%	0. .0%	587. .2%	44. .1%	0. .0%	44. .1%	2. .4%	0. .0%	2. .4%
WATER	0. .0%	84111. 66.4%	84111. 33.9%	0. .0%	8426. 66.4%	8426. 15.6%	0. .0%	17. 23.3%	17. 4.0%
TOTALS	121381.	126638.	248019.	41390.	12686.	54076.	355.	74.	429.

Table I-A-2. Water (m^3) and sediment (kg) loadings estimated by LANDRUN for each land use in Subwatershed 17B (area in ha)--Summer 1977

LAND USE	WATER PERV	WATER IMPER	WATER TOTAL	SEDIMENT PERV	DUST/DIRT IMPER	SEDIMENT TOTAL	AREA PERV	AREA IMPER	AREA TOTAL
INDUSTRIAL	11314. [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1127. [illegible]	39. 3.5%	13. 15.5%	52. 4.3%
COMMERCIAL	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	741. 1.3%	26. 2.3%	12. 13.9%	38. 3.2%
MED/DENS/RES	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	775. 1.4%	57. 5.1%	17. 20.2%	75. 6.2%
LO /DENS/RES	1666. 1.1%	103. .4%	1769. 1.0%	46. .1%	10. .4%	56. .1%	17. 1.5%	2. 2.4%	19. 1.6%
HI /DENS/RES	1856. 1.2%	426. 1.5%	2282. 1.3%	31. .1%	43. 1.5%	74. .1%	2. .2%	1. 1.7%	4. .3%
DEVELOPING	46213. 30.8%	963. 3.4%	47176. 26.5%	37368. 71.4%	97. 3.4%	37465. 68.0%	37. 3.3%	7. 7.7%	44. 3.5%
ROW CROPS	2611. 1.7%	0. .0%	2611. 1.5%	5737. 11.0%	0. .0%	5737. 10.4%	432. 38.8%	0. .0%	432. 35.5%
PK/REC/PASTR	29825. 19.9%	412. 1.5%	30237. 17.0%	5153. 9.9%	41. 1.5%	5194. 9.4%	343. 30.8%	8. 9.4%	351. 29.1%
FORESTS	2344. 1.6%	0. .0%	2344. 1.3%	187. .4%	0. .0%	187. .3%	72. 6.5%	0. .0%	72. 6.0%
WETLANDS	16410. 11.0%	0. .0%	16410. 9.2%	652. 1.2%	0. .0%	652. 1.2%	84. 7.5%	0. .0%	84. 7.0%
FEEDLOTS	2102. 1.4%	0. .0%	2102. 1.2%	1688. 3.2%	0. .0%	1688. 3.1%	6. .5%	0. .0%	6. .5%
WATER	0. .0%	9374. 33.3%	9374. 5.3%	0. .0%	939. 33.3%	939. 1.7%	0. .0%	2. 2.2%	2. .2%
FREEWAYS	0. .0%	4452. 15.8%	4452. 2.5%	0. .0%	446. 15.8%	446. .8%	0. .0%	23. 26.5%	23. 1.9%
TOTALS	149839.	28123.	177962.	52314.	2818.	55132.	1114.	86.	1200.

Table I-A-3. Water (m^3) and sediment (kg) loadings estimated by LANDRUN for each land use in Subwaterhsed 12C (area in ha)--Summer 1977

LAND USE	WATER PERV	WATER IMPER	WATER TOTAL	SEDIMENT PERV	DUST/DIRT IMPER	SEDIMENT TOTAL	AREA PERV	AREA IMPER	AREA TOTAL
INDUSTRIAL	2687. 2.9%	852. 4.7%	3539. 3.2%	12. .1%	85. 4.6%	97. .7%	1. .3%	2. 4.8%	4. .6%
COMMERCIAL	7356. 7.9%	1761. 9.6%	9117. 8.1%	57. .5%	176. 9.6%	233. 1.7%	5. 1.0%	5. 9.8%	10. 1.8%
MED/DENS/RES	22955. 24.5%	2742. 15.0%	25697. 22.9%	468. 4.0%	274. 15.0%	742. 5.5%	36. 6.9%	19. 40.9%	55. 9.6%
LO /DENS/RES	1324. 1.4%	83. .5%	1407. 1.3%	32. .3%	8. .4%	40. .3%	9. 1.8%	2. 3.7%	11. 1.9%
DEVELOPING	14661. 15.6%	489. 2.7%	15150. 13.5%	3855. 33.3%	48. 2.6%	3903. 29.1%	5. .9%	3. 7.3%	8. 1.4%
ROW CROPS	865. .9%	0. .0%	865. .8%	2148. 18.5%	0. .0%	2148. 16.0%	178. 33.8%	0. .0%	178. 31.1%
PK/REC/PASTR	35685. 38.1%	637. 3.5%	36322. 32.4%	3007. 26.0%	64. 3.5%	3071. 22.9%	207. 39.4%	13. 28.4%	220. 38.5%
FORESTS	2624. 2.8%	0. .0%	2624. 2.3%	199. 1.7%	0. .0%	199. 1.5%	54. 10.3%	0. .0%	54. 9.4%
WETLANDS	4040. 4.3%	0. .0%	4040. 3.6%	118. 1.0%	0. .0%	118. .9%	27. 5.2%	0. .0%	27. 4.8%
FEEDLOTS	1495. 1.6%	0. .0%	1495. 1.3%	1686. 14.6%	0. .0%	1686. 12.6%	3. .5%	0. .0%	3. .5%
WATER	0. .0%	11719. 64.1%	11719. 10.5%	0. .0%	1174. 64.2%	1174. 8.8%	0. .0%	2. 5.2%	2. .4%
TOTALS	93692.	18283.	111975.	11582.	1829.	13411.	526.	46.	571.

Table I-A-4. Water (m^3) and sediment (kg) loadings estimated by LANDRUN for each land use in Subwatershed 12D (area in ha)--Summer 1977

LAND USE	WATER PERV	WATER IMPER	WATER TOTAL	SEDIMENT PERV	DUST/DIRT IMPER	SEDIMENT TOTAL	AREA PERV	AREA IMPER	AREA TOTAL
COMMERCIAL	6896. 8.6%	1771. 47.8%	8667. 10.4%	84. .5%	178. 47.8%	262. 1.7%	19. 2.0%	5. 19.5%	24. 2.4%
MED/DENS/RES	10928. 13.7%	1395. 37.7%	12323. 14.7%	207. 1.3%	139. 37.4%	346. 2.2%	24. 2.5%	10. 41.1%	34. 3.5%
LO /DENS/RES	1965. 2.5%	102. 2.8%	2067. 2.5%	52. .3%	10. 2.7%	62. .4%	13. 1.4%	2. 8.9%	15. 1.5%
DEVELOPING	5079. 6.4%	135. 3.6%	5214. 6.2%	921. 6.0%	14. 3.8%	935. 5.9%	3. .3%	1. 4.0%	3. .3%
ROW CROPS	3395. 4.3%	0. .0%	3395. 4.1%	8730. 56.8%	0. .0%	8730. 55.5%	444. 46.4%	0. .0%	444. 45.3%
PK/REC/PASTR	38135. 47.7%	300. 8.1%	38435. 46.0%	3947. 25.7%	31. 8.3%	3978. 25.3%	305. 31.8%	6. 26.6%	311. 31.7%
FORESTS	6381. 8.0%	0. .0%	6381. 7.6%	596. 3.9%	0. .0%	596. 3.8%	116. 12.1%	0. .0%	116. 11.8%
WETLANDS	5922. 7.4%	0. .0%	5922. 7.1%	166. 1.1%	0. .0%	166. 1.1%	31. 3.2%	0. .0%	31. 3.2%
FEEDLOTS	1168. 1.5%	0. .0%	1168. 1.4%	664. 4.3%	0. .0%	664. 4.2%	3. .3%	0. .0%	3. .3%
TOTALS	79869.	3703.	83572.	15367.	372.	15739.	958.	23.	981.

Table I-A-5. Water (m^3) and sediment (kg) loadings estimated by LANDRUN for each land use in Subwatershed 11E (area in ha)--Summer 1977

LAND USE	WATER PERV	WATER IMPER	WATER TOTAL	SEDIMENT PERV	DUST/DIRT IMPER	SEDIMENT TOTAL	AREA PERV	AREA IMPER	AREA TOTAL
COMMERCIAL	2789. 2.0%	2266. 10.5%	5055. 3.1%	469. .5%	228. 10.6%	697. .8%	9. .6%	2. 7.4%	11. .7%
MED/DENS/RES	20150. 14.3%	14108. 65.5%	34258. 21.1%	6408. 7.5%	1413. 65.4%	7821. 8.9%	54. 3.4%	14. 58.0%	68. 4.3%
LO /DENS/RES	3470. 2.5%	570. 2.6%	4040. 2.5%	1410. 1.6%	57. 2.6%	1467. 1.7%	21. 1.3%	2. 7.8%	23. 1.4%
DEVELOPING	7879. 5.6%	533. 2.5%	8412. 5.2%	4383. 5.1%	53. 2.5%	4436. 5.0%	5. .3%	1. 4.4%	6. .4%
ROW CROPS	9152. 6.5%	0. .0%	9152. 5.6%	51125. 59.5%	0. .0%	51125. 58.1%	493. 31.5%	0. .0%	493. 31.0%
PK/REC/PASTR	51628. 36.7%	967. 4.5%	52595. 32.4%	11411. 13.3%	97. 4.5%	11508. 13.1%	472. 30.1%	5. 19.9%	477. 30.0%
FORESTS	16780. 11.9%	0. .0%	16780. 10.3%	1993. 2.3%	0. .0%	1993. 2.3%	373. 23.8%	0. .0%	373. 23.5%
WETLANDS	26143. 18.6%	0. .0%	26143. 16.1%	1376. 1.6%	0. .0%	1376. 1.6%	137. 8.7%	0. .0%	137. 8.6%
FEEDLOTS	2799. 2.0%	0. .0%	2799. 1.7%	7290. 8.5%	0. .0%	7290. 8.3%	3. .2%	0. .0%	3. .2%
WATER	0. .0%	3108. 14.4%	3108. 1.9%	0. .0%	311. 14.4%	311. .4%	0. .0%	1. 2.6%	1. .0%
TOTALS	140790.	21552.	162342.	85865.	2159.	88024.	1567.	25.	1592.

Table I-A-6. Water (m^3) and sediment (kg) loadings estimated by LANDRUN for each land use in Subwatershed 10A (area in ha)--Summer 1977

LAND USE	WATER PERV	WATER IMPER	WATER TOTAL	SEDIMENT PERV	DUST/DIRT IMPER	SEDIMENT TOTAL	AREA PERV	AREA IMPER	AREA TOTAL
INDUSTRIAL	83. .1%	3153. 1.0%	3236. .7%	6. .0%	347. 1.0%	353. .4%	0. .0%	1. .7%	1. .2%
COMMERCIAL	4053. 3.6%	64763. 19.8%	68816. 15.6%	1227. 1.9%	7118. 19.8%	8345. 8.3%	3. .6%	21. 15.3%	24. 4.0%
MED/DENS/RES	34361. 30.2%	195952. 60.0%	230313. 52.3%	44001. 68.4%	21539. 60.0%	65540. 65.4%	142. 30.7%	81. 58.6%	223. 37.2%
LO /DENS/RES	199. .2%	137. .0%	336. .1%	50. .1%	15. .0%	65. .1%	1. .2%	0. .2%	1. .2%
HI /DENS/RES	3428. 3.0%	20470. 6.3%	23898. 5.4%	1162. 1.8%	2250. 6.3%	3412. 3.4%	4. 1.0%	8. 5.6%	12. 2.0%
DEVELOPING	24385. 21.4%	10931. 3.3%	35316. 8.0%	15382. 23.9%	1201. 3.3%	16583. 16.5%	18. 4.0%	8. 6.0%	27. 4.4%
ROW CROPS	381. .3%	0. .0%	381. .1%	669. 1.0%	0. .0%	669. .7%	8. 1.7%	0. .0%	8. 1.3%
PK/REC/PASTR	25260. 22.2%	16625. 5.1%	41885. 9.5%	1022. 1.6%	1827. 5.1%	2849. 2.8%	136. 29.4%	15. 11.0%	151. 25.2%
FORESTS	0. .0%	0. .0%	0. .0%	0. .0%	0. .0%	0. .0%	8. 1.7%	0. .0%	8. 1.3%
WETLANDS	21212. 18.6%	0. .0%	21212. 4.8%	786. 1.2%	0. .0%	786. .8%	141. 30.5%	0. .0%	141. 23.5%
LANDFILL	386. .3%	0. .0%	386. .1%	7. .0%	0. .0%	7. .0%	1. .3%	0. .0%	1. .2%
WATER	0. .0%	14583. 4.5%	14583. 3.3%	0. .0%	1603. 4.5%	1603. 1.6%	0. .0%	3. 2.4%	3. .5%
TOTALS	113748.	326614.	440362.	64312.	35900.	100212.	462.	137.	599.

Table I-A-7. Water (m^3) and sediment (kg) loadings estimated by LANDRUN for each land use in Subwatershed 10B (area in ha)--Summer 1977

LAND USE	WATER PERV	WATER IMPER	WATER TOTAL	SEDIMENT PERV	DUST/DIRT IMPER	SEDIMENT TOTAL	AREA PERV	AREA IMPER	AREA TOTAL
INDUSTRIAL	499. .5%	1649. 3.9%	2148. 1.5%	2. .0%	181. 3.9%	183. 1.1%	0. .1%	5. 3.6%	5. 1.1%
COMMERCIAL	6230. 6.2%	5872. 14.1%	12102. 8.5%	73. .6%	645. 14.0%	718. 4.1%	4. 1.3%	17. 12.7%	21. 4.6%
MED/DENS/RES	55286. 55.2%	7904. 18.9%	63190. 44.5%	1627. 12.7%	869. 18.9%	2496. 14.3%	107. 32.5%	60. 45.7%	166. 36.3%
LO /DENS/RES	1873. 1.9%	68. .2%	1941. 1.4%	63. .5%	8. .2%	71. .4%	10. 3.0%	2. 1.2%	12. 2.5%
HI /DENS/RES	5193. 5.2%	1245. 3.0%	6438. 4.5%	30. .2%	137. 3.0%	167. 1.0%	4. 1.1%	5. 3.6%	8. 1.8%
DEVELOPING	14019. 14.0%	648. 1.6%	14667. 10.3%	2823. 22.0%	71. 1.5%	2894. 16.6%	4. 1.1%	5. 3.7%	9. 1.9%
ROW CROPS	2315. 2.3%	0. .0%	2315. 1.6%	6368. 49.7%	0. .0%	6368. 36.6%	70. 21.2%	0. .0%	70. 15.2%
PE/REC/PASTR	14583. 14.6%	323. .8%	14906. 10.5%	1817. 14.2%	36. .8%	1853. 10.7%	107. 32.7%	7. 5.6%	115. 25.0%
FORESTS	0. .0%	0. .0%	0. .0%	0. .0%	0. .0%	0. .0%	21. 6.3%	0. .0%	21. 4.5%
WETLANDS	187. .2%	0. .0%	187. .1%	2. .0%	0. .0%	2. .0%	2. .5%	0. .0%	2. .3%
WATER	0. .0%	19302. 46.2%	19302. 13.6%	0. .0%	2122. 46.2%	2122. 12.2%	0. .0%	4. 3.1%	4. 1.0%
FREEWAYS	0. .0%	4753. 11.4%	4753. 3.3%	0. .0%	522. 11.4%	522. 3.0%	0. .0%	27. 20.6%	27. 5.9%
TOTALS	100185.	41764.	141949.	12805.	4591.	17396.	329.	131.	459.

Table I-A-8. Water (m^3) and sediment (kg) loadings estimated by LANDRUN for each land use in Subwatershed 10C (area in ha)--Summer 1977

LAND USE	WATER PERV	WATER IMPER	WATER TOTAL	SEDIMENT PERV	DUST/DIRT IMPER	SEDIMENT TOTAL	AREA PERV	AREA IMPER	AREA TOTAL
INDUSTRIAL	84. .1%	145. 1.9%	229. .3%	0. .0%	15. 1.9%	15. .1%	0. .0%	0. 1.1%	0. .1%
COMMERCIAL	9362. 13.4%	2105. 27.2%	11467. 14.8%	97. .5%	211. 27.2%	308. 1.6%	10. 2.2%	5. 15.5%	16. 3.1%
MED/DENS/RES	15113. 21.7%	1459. 18.8%	16572. 21.4%	336. 1.8%	146. 18.8%	482. 2.5%	38. 8.1%	10. 29.2%	48. 9.5%
LO /DENS/RES	966. 1.4%	32. .4%	998. 1.3%	22. .1%	3. .4%	25. .1%	6. 1.4%	1. 1.9%	7. 1.4%
DEVELOPING	12810. 18.4%	294. 3.8%	13104. 16.9%	6793. 36.4%	29. 3.7%	6822. 35.1%	7. 1.5%	2. 5.9%	9. 1.8%
ROW CROPS	2985. 4.3%	0. .0%	2985. 3.9%	8577. 46.0%	0. .0%	8577. 44.2%	157. 33.5%	0. .0%	157. 31.2%
PE/REC/PASTR	18555. 26.7%	100. 1.3%	18655. 24.1%	2307. 12.4%	10. 1.3%	2317. 11.9%	159. 34.0%	2. 6.0%	161. 32.1%
FORESTS	4114. 5.9%	0. .0%	4114. 5.3%	351. 1.9%	0. .0%	351. 1.8%	64. 13.7%	0. .0%	64. 12.7%
WETLANDS	5628. 8.1%	0. .0%	5628. 7.3%	159. .9%	0. .0%	159. .8%	26. 5.5%	0. .0%	26. 5.1%
WATER	0. .0%	980. 12.6%	980. 1.3%	0. .0%	98. 12.6%	98. .5%	0. .0%	0. .6%	0. .1%
FREEWAYS	0. .0%	2635. 34.0%	2635. 3.4%	0. .0%	264. 34.0%	264. 1.4%	0. .2%	11. 34.5%	11. 2.2%
TOTALS	69617.	7750.	77367.	18650.	776.	19426.	467.	34.	502.

Table I-A-9. Water (m³) and sediment (kg) loadings estimated by LANDRUN for each land use in Subwatershed 10D (area in ha)-- Summer 1977

LAND USE	WATER PERV	WATER IMPER	WATER TOTAL	SEDIMENT PERV	DUST/DIRT IMPER	SEDIMENT TOTAL	AREA PERV	AREA IMPER	AREA TOTAL
INDUSTRIAL	9196. 3.7%	3674. 2.9%	12870. 3.4%	165. .1%	368. 2.9%	533. .3%	19. 1.3%	9. 6.9%	28. 1.8%
COMMERCIAL	17305. 6.9%	3603. 2.9%	20908. 5.6%	187. .1%	361. 2.9%	548. .4%	9. .6%	9. 6.8%	18. 1.1%
MED/DENS/RES	48704. 19.5%	6054. 4.8%	54758. 14.6%	3292. 2.3%	606. 4.8%	3898. 2.6%	152. 10.3%	41. 30.5%	193. 12.0%
LO /DENS/RES	2114. .9%	113. .1%	2227. .6%	102. .1%	11. .1%	113. .1%	20. 1.3%	2. 1.7%	22. 1.4%
HI /DENS/RES	217. .1%	61. .0%	278. .1%	5. .0%	6. .0%	11. .0%	1. .0%	0. .2%	1. .1%
DEVELOPING	82225. 33.0%	69689. 55.3%	151914. 40.5%	88698. 63.3%	6981. 55.3%	95679. 62.6%	75. 5.1%	20. 15.0%	96. 5.9%
ROW CROPS	3346. 1.3%	0. .0%	3345. .9%	29194. 20.8%	0. .0%	29194. 19.1%	313. 21.2%	0. .0%	313. 19.4%
PR/REC/PASTR	64926. 26.1%	492. .4%	65418. 17.4%	15516. 11.1%	49. .0%	15565. 10.2%	609. 41.3%	10. 7.4%	619. 38.5%
FORESTS	5562. 2.2%	0. .0%	5562. 1.5%	597. .4%	0. .0%	597. .4%	203. 13.8%	0. .0%	203. 12.6%
WETLANDS	13998. 5.6%	0. .0%	13998. 3.7%	832. .6%	0. .0%	832. .5%	72. 4.9%	0. .0%	72. 4.4%
FEEDLOTS	1594. .6%	0. .0%	1594. .4%	1603. 1.1%	0. .0%	1603. 1.0%	3. .2%	0. .0%	3. .2%
WATER	0. .0%	35305. 28.1%	35305. 9.4%	0. .0%	3545. 28.1%	3545. 2.3%	0. .0%	7. 5.3%	7. .5%
FREEWAYS	0. .0%	6920. 5.5%	6920. 1.8%	0. .0%	693. 5.5%	693. .5%	0. .0%	35. 26.1%	35. 2.2%
TOTALS	249187.	125981.	375178.	140191.	12620.	152811.	1475.	136.	1610.

Table I-A-10. Water (m³) and sediment (kg) loadings estimated by LANDRUN for each land use in Subwatershed 10E (area in ha)-- Summer 1977

LAND USE	WATER PERV	WATER IMPER	WATER TOTAL	SEDIMENT PERV	DUST/DIRT IMPER	SEDIMENT TOTAL	AREA PERV	AREA IMPER	AREA TOTAL
COMMERCIAL	442. .5%	4718. 6.5%	5160. 3.1%	33. .1%	472. 6.6%	505. .9%	0. .0%	2. 4.1%	2. .2%
MED/DENS/RES	23419. 25.4%	54308. 75.5%	77727. 47.4%	16736. 28.4%	5440. 75.5%	22176. 33.6%	88. 10.9%	28. 59.0%	116. 13.6%
LO /DENS/RES	1650. 1.8%	595. .8%	2245. 1.4%	826. 1.4%	58. .8%	884. 1.3%	9. 1.1%	1. 2.5%	10. 1.2%
DEVELOPING	20253. 22.0%	3686. 5.1%	23939. 14.6%	12386. 21.0%	370. 5.1%	12756. 19.3%	11. 1.3%	4. 8.0%	16. 1.7%
ROW CROPS	5080. 5.5%	0. .0%	5080. 3.1%	24973. 42.4%	0. .0%	24973. 37.8%	317. 39.3%	0. .0%	317. 37.1%
PR/REC/PASTR	18528. 20.1%	2475. 3.4%	21003. 12.8%	2966. 5.0%	248. 3.4%	3214. 4.9%	218. 27.1%	5. 10.6%	224. 26.2%
FORESTS	3264. 3.5%	0. .0%	3264. 2.0%	272. .5%	0. .0%	272. .4%	73. 9.0%	0. .0%	73. 8.5%
WETLANDS	18737. 20.3%	0. .0%	18737. 11.4%	677. 1.2%	0. .0%	677. 1.0%	90. 11.2%	0. .0%	90. 10.5%
WATER	0. .0%	4552. 6.3%	4552. 2.8%	0. .0%	455. 6.3%	455. .7%	0. .0%	1. 2.0%	1. .1%
FREEWAYS	0. .0%	1562. 2.2%	1562. 1.0%	0. .0%	156. 2.2%	156. .2%	0. .0%	6. 13.5%	6. .8%
TOTALS	92157.	71920.	164077.	58869.	7203.	66072.	806.	47.	853.

Table I-A-11. Water (m^3) and sediment (kg) loadings estimated by LANDRUN for each land use in Subwatershed 7A (area in ha)-- Summer 1977

LAND USE	WATER PERV	WATER IMPER	WATER TOTAL	SEDIMENT PERV	DUST/DIRT IMPER	SEDIMENT TOTAL	AREA PERV	AREA IMPER	AREA TOTAL
INDUSTRIAL	3395. 6.9%	97857. 20.0%	101252. 18.8%	325. .1%	11752. 20.0%	12077. 3.1%	2. .3%	28. 12.3%	30. 3.1%
COMMERCIAL	7574. 15.5%	148520. 30.3%	156094. 29.0%	1707. .5%	17835. 30.3%	19542. 5.0%	14. 1.9%	42. 18.7%	56. 5.7%
MED/DENS/RES	546. 1.1%	110435. 22.5%	110981. 20.6%	229. .1%	13261. 22.5%	13490. 3.5%	135. 17.8%	42. 18.8%	177. 18.0%
LO /DENS/RES	0. .0%	523. .1%	523. .1%	0. .0%	63. .1%	63. .0%	5. .7%	1. .3%	6. .6%
HI /DENS/RES	5. .0%	399. .1%	404. .1%	1. .0%	48. .1%	49. .0%	0. .0%	0. .1%	0. .0%
DEVELOPING	36356. 74.3%	16232. 3.3%	52588. 9.8%	328396. 99.3%	1949. 3.3%	330345. 84.8%	39. 5.1%	11. 4.7%	49. 5.0%
ROW CROPS	0. .0%	0. .0%	0. .0%	0. .0%	0. .0%	0. .0%	87. 11.5%	0. .0%	87. 8.9%
PE/REC/PASTR	861. 1.8%	9440. 1.9%	10301. 1.9%	30. .0%	1134. 1.9%	1164. .3%	384. 50.8%	7. 3.2%	391. 39.8%
FORESTS	0. .0%	0. .0%	0. .0%	0. .0%	0. .0%	0. .0%	68. 9.0%	0. .0%	68. 7.0%
WETLANDS	197. .4%	0. .0%	197. .0%	7. .0%	0. .0%	7. .0%	21. 2.8%	0. .0%	21. 2.2%
FEEDLOTS	25. .1%	0. .0%	25. .0%	22. .0%	0. .0%	22. .0%	0. .0%	0. .0%	0. .0%
WATER	0. .0%	72116. 14.7%	72116. 13.4%	0. .0%	8660. 14.7%	8660. 2.2%	0. .0%	16. 7.1%	16. 1.7%
FREEWAYS	0. .0%	34546. 7.0%	34546. 6.4%	0. .0%	4148. 7.1%	4148. 1.1%	0. .0%	79. 34.9%	79. 8.0%
TOTALS	48959.	490068.	539027.	330715.	58850.	389565.	756.	225.	981.

Table I-A-12. Water (m^3) and sediment (kg) loadings estimated by LANDRUN for each land use in Subwatershed 7B (area in ha)-- Summer 1977

LAND USE	WATER PERV	WATER IMPER	WATER TOTAL	SEDIMENT PERV	DUST/DIRT IMPER	SEDIMENT TOTAL	AREA PERV	AREA IMPER	AREA TOTAL
INDUSTRIAL	7325. 6.1%	2606. 6.1%	9931. 6.1%	84. .3%	288. 6.1%	373. 1.1%	41. 5.6%	7. 8.4%	48. 5.8%
COMMERCIAL	28818. 23.8%	10340. 24.2%	39158. 23.9%	255. .9%	1136. 24.2%	1391. 4.1%	19. 2.6%	29. 33.3%	49. 5.9%
MED/DENS/RES	12156. 10.0%	1658. 3.9%	13814. 8.4%	286. 1.0%	181. 3.9%	467. 1.4%	44. 5.9%	13. 14.2%	56. 6.8%
LO /DENS/RES	1433. 1.2%	30. .1%	1463. .9%	42. .1%	4. .1%	46. .1%	12. 1.6%	1. .6%	13. 1.6%
HI /DENS/RES	905. .7%	193. .4%	1098. .7%	6. .0%	21. .4%	27. .1%	3. .3%	1. .6%	3. .4%
DEVELOPING	12722. 10.5%	440. 1.0%	13162. 8.0%	5737. 19.6%	49. 1.0%	5786. 17.1%	9. 1.2%	3. 3.0%	12. 1.5%
ROW CROPS	4861. 4.0%	0. .0%	4861. 3.0%	14809. 50.6%	0. .0%	14809. 43.6%	144. 19.6%	0. .0%	144. 17.5%
PE/REC/PASTR	45784. 37.8%	281. .7%	46065. 28.1%	7940. 27.2%	33. .7%	7973. 23.5%	413. 56.4%	7. 7.5%	419. 51.1%
FORESTS	0. .0%	0. .0%	0. .0%	0. .0%	0. .0%	0. .0%	23. 3.2%	0. .0%	23. 2.8%
WETLANDS	558. .5%	0. .0%	558. .3%	18. .1%	0. .0%	18. .1%	6. .8%	0. .0%	6. .8%
LANDFILL	6062. 5.0%	0. .0%	6062. 3.7%	63. .2%	0. .0%	63. .2%	22. 3.0%	0. .0%	22. 2.6%
WATER	0. .0%	23210. 54.4%	23210. 14.2%	0. .0%	2552. 54.4%	2552. 7.5%	0. .0%	5. 6.0%	5. .6%
FREEWAYS	0. .0%	3904. 9.1%	3904. 2.4%	0. .0%	420. 9.1%	420. 1.3%	0. .0%	22. 25.1%	22. 2.7%
TOTALS	121033.	42684.	163717.	29240.	4691.	33931.	733.	88.	822.

Table I-A-13. Water (m³) and sediment (kg) loadings estimated by LANDRUN for each land use in Subwatershed 7C (area in ha)-- Summer 1977

LAND USE	WATER PERV	WATER IMPER	WATER TOTAL	SEDIMENT PERV	DUST/DIRT IMPER	SEDIMENT TOTAL	AREA PERV	AREA IMPER	AREA TOTAL
COMMERCIAL	3701. 2.4%	8654. 25.0%	12355. 6.7%	273. .3%	951. 26.0%	1224. 1.4%	2. .4%	20. 16.3%	22. 3.1%
MED/DENS/RES	73220. 48.2%	21235. 60.7%	94464. 49.8%	20207. 24.2%	2225. 60.7%	22432. 25.8%	272. 49.5%	78. 63.4%	348. 48.5%
LO /DENS/RES	771. .5%	40. .1%	811. .4%	108. .1%	4. .1%	112. .1%	4. .7%	0. .4%	5. .7%
HI /DENS/RES	504. .3%	335. 1.0%	839. .5%	18. .0%	37. 1.0%	55. .1%	0. .1%	1. .8%	1. .2%
DEVELOPING	47753. 31.4%	2022. 6.1%	49775. 26.8%	51264. 61.5%	222. 6.1%	51486. 59.1%	37. 6.2%	11. 8.5%	48. 6.7%
ROW CROPS	2262. 1.5%	0. .0%	2262. 1.2%	6554. 7.8%	0. .0%	6554. 7.5%	65. 12.0%	0. .0%	65. 9.0%
PG/OGT/PASTR	25882. 17.0%	2049. 6.1%	27931. 15.1%	4912. 5.9%	225. 6.1%	5137. 5.9%	193. 32.2%	12. 9.5%	205. 28.5%
FORESTS	11. .0%	0. .0%	11. .0%	31. .0%	0. .0%	31. .0%	17. 3.1%	0. .0%	17. 2.4%
WETLANDS	706. .5%	0. .0%	706. .4%	25. .0%	0. .0%	25. .0%	5. .9%	0. .0%	5. .7%
TOTALS	151876.	35330.	187206.	83387.	3664.	87051.	550.	123.	718.

Table I-A-14. Water (m³) and sediment (kg) loadings estimated by LANDRUN for each land use in Subwatershed 7D (area in ha)-- Summer 1977

LAND USE	WATER PERV	WATER IMPER	WATER TOTAL	SEDIMENT PERV	DUST/DIRT IMPER	SEDIMENT TOTAL	AREA PERV	AREA IMPER	AREA TOTAL
INDUSTRIAL	7258. 5.5%	3285. 5.4%	10358. 5.5%	24. .0%	373. 5.4%	397. .4%	6. .5%	9. 3.5%	15. 1.1%
COMMERCIAL	6576. 5.0%	14169. 24.5%	20745. 11.2%	58. .1%	1521. 24.5%	1579. 1.5%	5. .4%	60. 15.3%	65. 3.2%
MED/DENS/RES	27108. 20.7%	20566. 35.7%	47674. 25.9%	1477. 1.6%	2471. 35.7%	4167. 4.4%	626. 54.3%	156. 61.7%	782. 55.0%
LO /DENS/RES	0. .0%	18. .0%	18. .0%	0. .0%	2. .0%	2. .0%	5. .4%	0. .1%	5. .4%
HI /DENS/RES	348. .3%	105. .2%	453. .2%	2. .0%	13. .2%	15. .0%	1. .0%	0. .0%	1. .1%
DEVELOPING	88107. 67.1%	2597. 4.5%	90702. 49.2%	88153. 97.4%	312. 4.5%	88465. 91.7%	71. 6.2%	20. 7.8%	91. 6.5%
R/W CROPS	0. .0%	0. .0%	0. .0%	0. .0%	0. .0%	0. .0%	71. 6.2%	0. .0%	71. 5.1%
PG/OG/PASTR	0. .0%	1026. 1.8%	1026. .5%	0. .0%	126. 1.8%	126. .1%	247. 21.4%	23. 9.3%	271. 19.3%
FORESTS	0. .0%	0. .0%	0. .0%	0. .0%	0. .0%	0. .0%	53. 4.6%	0. .0%	53. 3.4%
WETLANDS	1257. 1.0%	0. .0%	1257. .7%	10. .0%	0. .0%	10. .0%	51. 4.1%	0. .0%	51. 3.6%
LANDFILL	21. .0%	0. .0%	21. .0%	0. .0%	0. .0%	0. .0%	0. .0%	0. .0%	0. .0%
WATER	0. .0%	16095. 27.4%	16095. 8.5%	0. .0%	1852. 27.4%	1852. 2.1%	0. .0%	4. 1.4%	4. .3%
TOTALS	131287.	57671.	188553.	87672.	6927.	96655.	1156.	253.	1409.

Table I-6-13. Water (m^3) and sediment (kg) loadings estimated by LANDRUN for each land use in [illegible] TC basin in [illegible] Summer 1977

LAND USE	WATER PERV	WATER IMPER	WATER TOTAL	SEDIMENT PERV	DUST/DIRT IMPER	SEDIMENT TOTAL	AREA PERV	AREA IMPER	AREA TOTAL
INDUSTRIAL	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
COMMERCIAL	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
MED/DENS/RES	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
LO /DENS/RES	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
DEVELOPING	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
ROW CROPS	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
FORESTS	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
WATER	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
FREEWAY	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
TOTALS	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Table I-6-14. Water (m^3) and sediment (kg) loadings estimated by LANDRUN for each land use in [illegible] TC basin in [illegible] Summer 1977

LAND USE	WATER PERV	WATER IMPER	WATER TOTAL	SEDIMENT PERV	DUST/DIRT IMPER	SEDIMENT TOTAL	AREA PERV	AREA IMPER	AREA TOTAL
INDUSTRIAL	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
COMMERCIAL	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
MED/DENS/RES	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
LO /DENS/RES	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
DEVELOPING	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
ROW CROPS	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
FORESTS	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
WETLANDS	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
FEEDLOTS	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
WATER	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
TOTALS	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Table I-A-17. Water (m^3) and sediment (kg) loadings estimated by LANDRUN for each land use in Subwatershed 7G (area in ha)--Summer 1977

LAND USE	WATER PERV	WATER IMPER	WATER TOTAL	SEDIMENT PERV	DUST/DIRT IMPER	SEDIMENT TOTAL	AREA PERV	AREA IMPER	AREA TOTAL
INDUSTRIAL	4208. 2.1%	11938. 31.1%	16146. 6.9%	21. .0%	1312. 31.1%	1333. 1.0%	3. .2%	34. 23.7%	36. 2.7%
COMMERCIAL	31306. 15.9%	9709. 25.3%	41015. 17.4%	453. .3%	1067. 25.3%	1520. 1.1%	38. 3.2%	27. 19.3%	65. 4.9%
MED/DENS/RES	23601. 12.0%	3430. 8.9%	27031. 11.5%	1051. .8%	378. 8.9%	1429. 1.0%	86. 7.2%	26. 18.2%	112. 8.3%
LO /DENS/RES	3019. 1.5%	86. .2%	3105. 1.3%	132. .1%	9. .2%	141. .1%	18. 1.5%	2. 1.4%	20. 1.5%
HI /DENS/RES	1976. 1.0%	422. 1.1%	2398. 1.0%	5. .0%	47. 1.1%	52. .0%	1. .1%	2. 1.1%	3. .2%
DEVELOPING	63605. 32.3%	1552. 4.0%	65157. 27.7%	64963. 48.0%	171. 4.0%	65134. 46.7%	76. 6.3%	12. 8.2%	88. 6.5%
ROW CROPS	12778. 6.5%	0. .0%	12778. 5.4%	54788. 40.5%	0. .0%	54788. 39.3%	381. 31.8%	0. .0%	381. 28.4%
PK/REC/PASTR	47920. 24.3%	295. .8%	48215. 20.5%	12702. 9.4%	32. .8%	12734. 9.1%	421. 35.0%	7. 4.7%	428. 31.8%
FORESTS	0. .0%	0. .0%	0. .0%	0. .0%	0. .0%	0. .0%	120. 10.0%	0. .0%	120. 8.9%
WETLANDS	7906. 4.0%	0. .0%	7906. 3.4%	340. .3%	0. .0%	340. .2%	55. 4.6%	0. .0%	55. 4.1%
FEEDLOTS	525. .3%	0. .0%	525. .2%	779. .6%	0. .0%	779. .6%	1. .1%	0. .0%	1. .1%
WATER	0. .0%	5345. 13.9%	5345. 2.3%	0. .0%	588. 13.9%	588. .4%	0. .0%	1. .9%	1. .1%
FREEWAYS	0. .0%	5654. 14.7%	5654. 2.4%	0. .0%	621. 14.7%	621. .4%	0. .0%	32. 22.5%	32. 2.4%
TOTALS	196844.	38431.	235275.	135234.	4225.	139459.	1201.	142.	1343.

Table I-A-18. Water (m^3) and sediment (kg) loadings estimated by LANDRUN for each land use in Subwatershed 7H (area in ha)--Summer 1977

LAND USE	WATER PERV	WATER IMPER	WATER TOTAL	SEDIMENT PERV	DUST/DIRT IMPER	SEDIMENT TOTAL	AREA PERV	AREA IMPER	AREA TOTAL
INDUSTRIAL	27. .1%	1097. .6%	1124. .5%	2. .0%	121. .6%	123. .1%	0. .0%	0. .4%	0. .2%
COMMERCIAL	5746. 11.3%	48920. 25.7%	54666. 22.7%	1449. 1.2%	5378. 25.7%	6827. 4.8%	4. 2.3%	17. 20.1%	21. 8.3%
MED/DENS/RES	25606. 50.3%	116543. 61.2%	142149. 58.9%	28355. 23.5%	12811. 61.2%	41166. 29.0%	110. 66.0%	53. 62.3%	162. 64.7%
HI /DENS/RES	3398. 6.7%	16076. 8.4%	19474. 8.1%	2006. 1.7%	1767. 8.4%	3773. 2.7%	5. 2.8%	7. 7.8%	11. 4.5%
DEVELOPING	10610. 20.8%	3760. 2.0%	14370. 6.0%	88467. 73.2%	413. 2.0%	88880. 62.7%	8. 4.9%	3. 4.0%	12. 4.6%
ROW CROPS	7. .0%	0. .0%	7. .0%	10. .0%	0. .0%	10. .0%	0. .2%	0. .0%	0. .1%
PK/REC/PASTR	5118. 10.1%	3913. 2.1%	9031. 3.7%	570. .5%	430. 2.1%	1000. .7%	35. 21.2%	4. 5.2%	40. 15.8%
FORESTS	0. .0%	0. .0%	0. .0%	0. .0%	0. .0%	0. .0%	1. .6%	0. .0%	1. .4%
WETLANDS	396. .8%	0. .0%	396. .2%	16. .0%	0. .0%	16. .0%	3. 1.9%	0. .0%	3. 1.3%
TOTALS	50908.	190309.	241217.	120875.	20920.	141795.	166.	85.	251.

Table I-A-19. Water (m^3) and sediment (kg) loadings estimated by LANDRUN for each land use in Subwatershed 11A (area in ha)--Summer 1977

LAND USE	WATER PERV	WATER IMPER	WATER TOTAL	SEDIMENT PERV	DUST/DIRT IMPER	SEDIMENT TOTAL	AREA PERV	AREA IMPER	AREA TOTAL
COMMERCIAL	1113. 2.5%	249. 4.0%	1362. 2.7%	22. .1%	24. 3.9%	46. .1%	6. 1.1%	1. 2.7%	6. 1.2%
MED/DENS/RES	6985. 15.5%	627. 10.2%	7612. 14.9%	104. .3%	63. 10.2%	167. .5%	8. 1.7%	4. 18.0%	13. 2.4%
LO /DENS/RES	4194. 9.3%	115. 1.9%	4309. 8.4%	79. .3%	12. 1.9%	91. .3%	11. 2.1%	2. 10.0%	13. 2.5%
DEVELOPING	1595. 3.5%	45. .7%	1640. 3.2%	978. 3.2%	5. .8%	983. 3.2%	1. .1%	0. 1.3%	1. .2%
ROW CROPS	6122. 13.6%	0. .0%	6122. 12.0%	27093. 89.9%	0. .0%	27093. 88.1%	358. 71.3%	0. .0%	358. 68.1%
PK/REC/PASTR	22187. 49.3%	744. 12.1%	22931. 44.8%	1745. 5.8%	75. 12.2%	1820. 5.9%	79. 15.7%	15. 64.2%	94. 17.9%
FORESTS	1092. 2.4%	0. .0%	1092. 2.1%	67. .2%	0. .0%	67. .2%	32. 6.4%	0. .0%	32. 6.2%
WETLANDS	1761. 3.9%	0. .0%	1761. 3.4%	36. .1%	0. .0%	36. .1%	8. 1.5%	0. .0%	8. 1.5%
WATER	0. .0%	4370. 71.1%	4370. 8.5%	0. .0%	438. 71.0%	438. 1.4%	0. .0%	1. 3.8%	1. .2%
TOTALS	45049.	6150.	51199.	30124.	617.	30741.	503.	24.	527.

Table I-A-20. Water (m^3) and sediment (kg) loadings estimated by LANDRUN for each land use in Subwatershed 11B (area in ha)--Summer 1977

LAND USE	WATER PERV	WATER IMPER	WATER TOTAL	SEDIMENT PERV	DUST/DIRT IMPER	SEDIMENT TOTAL	AREA PERV	AREA IMPER	AREA TOTAL
COMMERCIAL	378. .4%	698. 1.1%	1076. .6%	2. .0%	70. 1.1%	72. .1%	0. .0%	2. 4.4%	2. .2%
MED/DENS/RES	20420. 19.5%	1907. 2.9%	22327. 13.1%	953. 1.3%	191. 2.9%	1144. 1.4%	51. 6.3%	13. 32.2%	64. 7.6%
LO /DENS/RES	1789. 1.7%	64. .1%	1853. 1.1%	35. .0%	7. .1%	42. .1%	11. 1.3%	1. 3.3%	12. 1.4%
HI /DENS/RES	803. .8%	176. .3%	979. .6%	3. .0%	18. .3%	21. .0%	1. .1%	1. 1.5%	1. .2%
DEVELOPING	33164. 31.6%	725. 1.1%	33889. 19.9%	43988. 58.3%	73. 1.1%	44061. 53.7%	18. 2.2%	5. 12.2%	23. 2.7%
ROW CROPS	4925. 4.7%	0. .0%	4925. 2.9%	21793. 28.9%	0. .0%	21793. 26.6%	281. 34.6%	0. .0%	281. 33.0%
PK/REC/PASTR	33414. 31.9%	296. .4%	33710. 19.8%	6028. 8.0%	30. .5%	6058. 7.4%	321. 39.5%	6. 15.0%	327. 38.4%
FORESTS	1298. 1.2%	0. .0%	1298. .8%	83. .1%	0. .0%	83. .1%	88. 10.8%	0. .0%	88. 10.3%
WETLANDS	5391. 5.1%	0. .0%	5391. 3.2%	184. .2%	0. .0%	184. .2%	34. 4.2%	0. .0%	34. 4.0%
FEEDLOTS	3204. 3.1%	0. .0%	3204. 1.9%	2347. 3.1%	0. .0%	2347. 2.9%	7. .9%	0. .0%	7. .8%
WATER	0. .0%	61998. 94.1%	61998. 36.3%	0. .0%	6210. 94.1%	6210. 7.6%	0. .0%	13. 31.4%	13. 1.5%
TOTALS	104786.	65864.	170650.	75416.	6599.	82015.	812.	40.	852.

Table I-A-21. Water (m^3) and sediment (kg) loadings estimated by LANDRUN for each land use in Subwatershed 11C (area in ha)--Summer 1977

LAND USE	WATER PERV	WATER IMPER	WATER TOTAL	SEDIMENT PERV	DUST/DIRT IMPER	SEDIMENT TOTAL	AREA PERV	AREA IMPER	AREA TOTAL
COMMERCIAL	2831. 2.7%	667. 12.0%	3498. 3.2%	72. .1%	66. 11.9%	138. .3%	8. 1.1%	2. 6.8%	10. 1.3%
MED/DENS/RES	29743. 28.7%	2418. 43.4%	32161. 29.5%	1265. 2.4%	242. 43.5%	1507. 2.9%	75. 10.1%	17. 65.9%	91. 11.9%
LO /DENS/RES	1517. 1.5%	50. .9%	1567. 1.4%	52. .1%	5. .9%	57. .1%	11. 1.5%	1. 4.0%	12. 1.5%
DEVELOPING	24852. 24.0%	456. 8.2%	25308. 23.2%	18312. 35.4%	45. 8.1%	18357. 35.1%	13. 1.7%	3. 12.4%	16. 2.1%
ROW CROPS	6591. 6.4%	0. .0%	6591. 6.0%	23519. 45.5%	0. .0%	23519. 45.0%	299. 40.3%	0. .0%	299. 39.0%
PK/REC/PASTR	28551. 27.6%	115. 2.1%	28666. 26.3%	5486. 10.6%	11. 2.0%	5497. 10.5%	234. 31.6%	2. 9.3%	236. 30.8%
FORESTS	5113. 4.9%	0. .0%	5113. 4.7%	460. .9%	0. .0%	460. .9%	90. 12.2%	0. .0%	90. 11.8%
WETLANDS	1455. 1.4%	0. .0%	1455. 1.3%	28. .1%	0. .0%	28. .1%	6. .9%	0. .0%	6. .8%
FEEDLOTS	2827. 2.7%	0. .0%	2827. 2.6%	2490. 4.8%	0. .0%	2490. 4.8%	5. .7%	0. .0%	5. .7%
WATER	0. .0%	1868. 33.5%	1868. 1.7%	0. .0%	187. 33.6%	187. .4%	0. .0%	0. 1.5%	0. .0%
TOTALS	103480.	5574.	109054.	51684.	556.	52240.	740.	25.	765.

Table I-A-22. Water (m^3) and sediment (kg) loadings estimated by LANDRUN for each land use in Subwatershed 8A (area in ha)--Summer 1977

LAND USE	WATER PERV	WATER IMPER	WATER TOTAL	SEDIMENT PERV	DUST/DIRT IMPER	SEDIMENT TOTAL	AREA PERV	AREA IMPER	AREA TOTAL
INDUSTRIAL	54. .1%	2304. .8%	2358. .7%	7. .0%	254. .8%	261. .1%	0. .0%	1. .4%	1. .1%
COMMERCIAL	600. 1.1%	19906. 6.9%	20506. 6.0%	252. .1%	2195. 6.9%	2447. .9%	6. 1.5%	5. 3.5%	12. 2.0%
MED/DENS/RES	14151. 25.1%	183197. 63.6%	197348. 57.3%	14107. 5.7%	20203. 63.6%	34310. 12.3%	148. 33.4%	66. 42.3%	214. 35.7%
LO /DENS/RES	116. .2%	321. .1%	437. .1%	70. .0%	35. .1%	105. .0%	2. .4%	0. .2%	2. .4%
HI /DENS/RES	1487. 2.6%	30127. 10.5%	31614. 9.2%	679. .3%	3323. 10.5%	4002. 1.4%	8. 1.9%	9. 6.0%	18. 2.9%
DEVELOPING	24033. 42.7%	12969. 4.5%	37002. 10.8%	231996. 93.5%	1431. 4.5%	233427. 83.4%	19. 4.3%	8. 5.1%	27. 4.5%
ROW CROPS	0. .0%	0. .0%	0. .0%	0. .0%	0. .0%	0. .0%	16. 3.5%	0. .0%	16. 2.6%
PK/REC/PASTR	15772. 28.0%	3903. 1.4%	19675. 5.7%	924. .4%	431. 1.4%	1355. .5%	222. 50.0%	17. 10.8%	239. 39.8%
FORESTS	0. .0%	0. .0%	0. .0%	0. .0%	0. .0%	0. .0%	18. 4.1%	0. .0%	18. 3.1%
WETLANDS	85. .2%	0. .0%	85. .0%	6. .0%	0. .0%	6. .0%	4. .9%	0. .0%	4. .6%
WATER	0. .0%	13644. 4.7%	13644. 4.0%	0. .0%	1505. 4.7%	1505. .5%	0. .0%	3. 1.9%	3. .5%
FREEWAYS	0. .0%	21525. 7.5%	21525. 6.3%	0. .0%	2374. 7.5%	2374. .8%	0. .0%	46. 29.8%	46. 7.7%
TOTALS	56298.	287896.	344194.	248041.	31751.	279792.	444.	155.	599.

Table I-A-23. Water (m^3) and sediment (kg) loadings estimated by LANDRUN for each land use in Subwatershed 8B (area in ha)--Summer 1977

LAND USE	WATER PERV	WATER IMPER	WATER TOTAL	SEDIMENT PERV	DUST/DIRT IMPER	SEDIMENT TOTAL	AREA PERV	AREA IMPER	AREA TOTAL
INDUSTRIAL	1878. 2.6%	31352. 9.6%	33230. 8.3%	342. .2%	3457. 9.6%	3799. 1.7%	2. .3%	8. 7.6%	11. 1.3%
COMMERCIAL	4152. 5.7%	147919. 45.1%	152071. 37.9%	1793. 1.0%	16313. 45.1%	18106. 8.1%	27. 3.6%	40. 35.7%	67. 7.8%
MED/DENS/RES	7522. 10.3%	86638. 26.4%	94160. 23.5%	4303. 2.3%	9555. 26.4%	13858. 6.2%	81. 10.9%	31. 27.8%	112. 13.1%
LO /DENS/RES	362. .5%	753. .2%	1115. .3%	330. .2%	83. .2%	413. .2%	7. .9%	1. .7%	8. .9%
HI /DENS/RES	1867. 2.6%	40752. 12.4%	42619. 10.6%	797. .4%	4494. 12.4%	5291. 2.4%	12. 1.6%	13. 11.2%	25. 2.9%
DEVELOPING	40988. 56.2%	18633. 5.7%	59621. 14.9%	177748. 95.4%	2055. 5.7%	179803. 80.8%	38. 5.1%	11. 10.3%	50. 5.8%
ROW CROPS	0. .0%	0. .0%	0. .0%	0. .0%	0. .0%	0. .0%	116. 15.6%	0. .0%	116. 13.6%
PK/REC/PASTR	13634. 18.7%	1713. .5%	15347. 3.8%	839. .5%	189. .5%	1028. .5%	373. 50.3%	7. 6.6%	381. 44.6%
FORESTS	0. .0%	0. .0%	0. .0%	0. .0%	0. .0%	0. .0%	47. 6.3%	0. .0%	47. 5.5%
WETLANDS	655. .9%	0. .0%	655. .2%	34. .0%	0. .0%	34. .0%	25. 3.3%	0. .0%	25. 2.9%
LANDFILL	1905. 2.6%	0. .0%	1905. .5%	39. .0%	0. .0%	39. .0%	13. 1.8%	0. .0%	13. 1.6%
WATER	0. .0%	396. .1%	396. .1%	0. .0%	44. .1%	44. .0%	0. .0%	0. .1%	0. .0%
TOTALS	72963.	328156.	401119.	186225.	36190	222415.	741.	112.	853.

Table I-A-24. Water (m^3) and sediment (kg) loadings estimated by LANDRUN for each land use in Subwatershed 8C (area in ha)--Summer 1977

LAND USE	WATER PERV	WATER IMPER	WATER TOTAL	SEDIMENT PERV	DUST/DIRT IMPER	SEDIMENT TOTAL	AREA PERV	AREA IMPER	AREA TOTAL
INDUSTRIAL	8425. 4.4%	3214. 6.5%	11639. 4.8%	60. .1%	354. 6.5%	414. .4%	13. 1.4%	9. 7.9%	22. 2.2%
COMMERCIAL	53642. 27.9%	22036. 44.4%	75678. 31.3%	698. .7%	2422. 44.4%	3120. 3.1%	37. 4.1%	62. 54.0%	99. 9.8%
MED/DENS/RES	8329. 4.3%	1205. 2.4%	9534. 3.9%	349. .4%	132. 2.4%	481. .5%	34. 3.8%	9. 7.9%	43. 4.3%
LO /DENS/RES	1388. .7%	40. .1%	1428. .6%	30. .0%	4. .1%	34. .0%	9. 1.0%	1. .8%	10. 1.0%
HI /DENS/RES	12913. 6.7%	2540. 5.1%	15453. 6.4%	111. .1%	279. 5.1%	390. .4%	10. 1.1%	10. 8.3%	19. 1.9%
DEVELOPING	62075. 32.3%	2096. 4.2%	64171. 26.5%	68941. 72.1%	230. 4.2%	69171. 68.4%	47. 5.2%	16. 13.7%	62. 6.2%
ROW CROPS	6084. 3.2%	0. .0%	6084. 2.5%	21010. 22.0%	0. .0%	21010. 20.8%	258. 28.8%	0. .0%	258. 25.5%
PK/REC/PASTR	29966. 15.6%	202. .4%	30168. 12.5%	4237. 4.4%	23. .4%	4260. 4.2%	284. 31.7%	5. 3.9%	288. 28.5%
FORESTS	0. .0%	0. .0%	0. .0%	0. .0%	0. .0%	0. .0%	135. 15.0%	0. .0%	135. 13.3%
WETLANDS	9294. 4.8%	0. .0%	9294. 3.8%	199. .2%	0. .0%	199. .2%	70. 7.8%	0. .0%	70. 6.9%
FEEDLOTS	71. .0%	0. .0%	71. .0%	24. .0%	0. .0%	24. .0%	0. .0%	0. .0%	0. .0%
WATER	0. .0%	18335. 36.9%	18335. 7.6%	0. .0%	2015. 36.9%	2015. 2.0%	0. .0%	4. 3.6%	4. .4%
TOTALS	192187.	49668.	241855.	95659.	5459.	101118.	896.	116.	1011.

Table I-A-25. Water (m^3) and sediment (kg) loadings estimated by LANDRUN for each land use in Subwatershed 9 (area in ha)--Summer 1977

LAND USE	WATER PERV	WATER IMPER	WATER TOTAL	SEDIMENT PERV	DUST/DIRT IMPER	SEDIMENT TOTAL	AREA PERV	AREA IMPER	AREA TOTAL
INDUSTRIAL	1875. 2.3%	66226. 9.6%	68101. 8.8%	237. .1%	7303. 9.6%	7540. 2.1%	1. .4%	18. 7.7%	19. 3.4%
COMMERCIAL	4892. 5.9%	151926. 22.0%	156818. 20.2%	2002. .7%	16754. 22.0%	18756. 5.1%	41. 12.6%	41. 17.6%	82. 14.7%
MED/DENS/RES	26697. 32.1%	297535. 43.0%	324232. 41.9%	14907. 5.2%	32811. 43.0%	47718. 13.1%	121. 37.5%	107. 45.9%	227. 41.0%
LO /DENS/RES	80. .1%	202. .0%	282. .0%	60. .0%	22. .0%	82. .0%	1. .3%	0. .1%	1. .2%
HI /DENS/RES	4706. 5.7%	76307. 11.0%	81013. 10.5%	2261. .8%	8415. 11.0%	10676. 2.9%	14. 4.4%	23. 10.1%	38. 6.8%
DEVELOPING	30852. 37.1%	19412. 2.8%	50264. 6.5%	269575. 93.2%	2140. 2.8%	271715. 74.3%	10. 3.1%	12. 5.1%	22. 3.9%
ROW CROPS	0. .0%	0. .0%	0. .0%	0. .0%	0. .0%	0. .0%	1. .4%	0. .0%	1. .2%
PK/REC/PASTR	11920. 14.3%	28837. 4.2%	40757. 5.3%	243. .1%	3180. 4.2%	3423. .9%	115. 35.9%	21. 8.9%	136. 24.5%
FORESTS	0. .0%	0. .0%	0. .0%	0. .0%	0. .0%	0. .0%	2. .8%	0. .0%	2. .4%
WETLANDS	10. .0%	0. .0%	10. .0%	0. .0%	0. .0%	0. .0%	1. .2%	0. .0%	1. .1%
LANDFILL	2179. 2.6%	0. .0%	2179. .3%	36. .0%	0. .0%	36. .0%	15. 4.5%	0. .0%	15. 2.6%
WATER	0. .0%	9530. 1.4%	9530. 1.2%	0. .0%	1051. 1.4%	1051. .3%	0. .0%	2. .9%	2. .4%
FREEWAYS	0. .0%	41469. 6.0%	41469. 5.4%	0. .0%	4573. 6.0%	4573. 1.3%	0. .0%	9. 3.8%	9. 1.6%
TOTALS	83211.	691444.	774655.	289321.	76249.	365570.	322.	233.	555.

Table I-A-26. Water (m^3) and sediment (kg) loadings estimated by LANDRUN for each land use in Subwatershed 6A (area in ha)--Summer 1977

LAND USE	WATER PERV	WATER IMPER	WATER TOTAL	SEDIMENT PERV	DUST/DIRT IMPER	SEDIMENT TOTAL	AREA PERV	AREA IMPER	AREA TOTAL
INDUSTRIAL	1705. .9%	51265. 6.8%	52970. 5.6%	118. .1%	5932. 6.8%	6050. 3.1%	1. .2%	18. 4.6%	20. 2.0%
COMMERCIAL	23099. 11.9%	192243. 25.5%	215342. 22.7%	3773. 3.5%	22246. 25.5%	26019. 13.3%	17. 3.0%	69. 17.3%	86. 8.9%
MED/DENS/RES	64007. 33.0%	380539. 50.6%	444546. 47.0%	67925. 62.2%	44034. 50.6%	111959. 57.0%	290. 50.7%	164. 41.1%	454. 46.8%
LO /DENS/RES	34. .0%	19. .0%	53. .0%	2. .0%	2. .0%	4. .0%	0. .0%	0. .0%	0. .0%
HI /DENS/RES	6022. 3.1%	39414. 5.2%	45436. 4.8%	1160. 1.1%	4561. 5.2%	5721. 2.9%	12. 2.2%	15. 3.9%	28. 2.9%
DEVELOPING	10873. 5.6%	4160. .6%	15033. 1.6%	24164. 22.1%	482. .6%	24646. 12.6%	6. 1.0%	4. .9%	10. 1.0%
PK/REC/PASTR	76983. 39.7%	60642. 8.1%	137625. 14.5%	11602. 10.6%	7017. 8.1%	18619. 9.5%	205. 35.8%	87. 21.9%	292. 30.1%
FORESTS	0. .0%	0. .0%	0. .0%	0. .0%	0. .0%	0. .0%	4. .6%	0. .0%	4. .4%
LANDFILL	11313. 5.8%	0. .0%	11313. 1.2%	502. .5%	0. .0%	502. .3%	37. 6.4%	0. .0%	37. 3.8%
WATER	0. .0%	5867. .8%	5867. .6%	0. .0%	679. .8%	679. .3%	0. .0%	1. .3%	1. .1%
FREEWAYS	0. .0%	18458. 2.5%	18458. 1.9%	0. .0%	2136. 2.5%	2136. 1.1%	0. .0%	40. 10.0%	40. 4.1%
TOTALS	194036.	752607.	946643.	109246.	87089.	196335.	572.	398.	970.

Table I-A-27. Water (m^3) and sediment (kg) loadings estimated by LANDRUN for each land use in Subwatershed 6B (area in ha)--Summer 1977

LAND USE	WATER PERV	WATER IMPER	WATER TOTAL	SEDIMENT PERV	DUST/DIRT IMPER	SEDIMENT TOTAL	AREA PERV	AREA IMPER	AREA TOTAL
INDUSTRIAL	13839. 4.5%	100737. 13.3%	114576. 10.7%	575. .6%	11657. 13.3%	12232. 6.5%	11. 1.4%	48. 9.3%	59. 4.5%
COMMERCIAL	74212. 23.9%	247597. 32.7%	321809. 30.2%	7268. 7.3%	28651. 32.7%	35919. 19.2%	81. 10.0%	118. 23.0%	199. 15.1%
MED/DENS/RES	110468. 35.6%	276116. 36.5%	386584. 36.2%	43486. 43.7%	31950. 36.5%	75436. 40.3%	341. 42.2%	198. 38.4%	539. 40.7%
HI /DENS/RES	17422. 5.6%	33409. 4.4%	50831. 4.8%	1416. 1.4%	3865. 4.4%	5281. 2.8%	14. 1.7%	21. 4.0%	34. 2.6%
DEVELOPING	39526. 12.7%	10506. 1.4%	50032. 4.7%	43354. 43.5%	1216. 1.4%	44570. 23.8%	25. 3.1%	11. 2.2%	36. 2.8%
PK/REC/PASTR	51656. 16.6%	25094. 3.3%	76750. 7.2%	3400. 3.4%	2904. 3.3%	6304. 3.4%	308. 38.1%	36. 7.0%	344. 26.0%
FORESTS	0. .0%	0. .0%	0. .0%	0. .0%	0. .0%	0. .0%	11. 1.4%	0. .0%	11. .8%
WETLANDS	2569. .8%	0. .0%	2569. .2%	95. .1%	0. .0%	95. .1%	13. 1.6%	0. .0%	13. 1.0%
LANDFILL	950. .3%	0. .0%	950. .1%	11. .0%	0. .0%	11. .0%	3. .4%	0. .0%	3. .3%
WATER	0. .0%	35077. 4.6%	35077. 3.3%	0. .0%	4059. 4.6%	4059. 2.2%	0. .0%	8. 1.5%	8. .6%
FREEWAYS	0. .0%	28110. 3.7%	28110. 2.6%	0. .0%	3253. 3.7%	3253. 1.7%	0. .0%	76. 14.7%	76. 5.7%
TOTALS	310642.	756646.	1067288.	99605.	87555.	187160.	808.	516.	1323.

Table I-A-28. Water (m^3) and sediment (kg) loadings estimated by LANDRUN for each land use in Subwatershed 6C (area in ha)--Summer 1977

LAND USE	WATER PERV	WATER IMPER	WATER TOTAL	SEDIMENT PERV	DUST/DIRT IMPER	SEDIMENT TOTAL	AREA PERV	AREA IMPER	AREA TOTAL
INDUSTRIAL	281. .2%	1246. 3.6%	1527. .7%	1. .0%	144. 3.6%	145. .3%	0. .0%	3. 2.0%	4. .5%
COMMERCIAL	26751. 15.1%	11903. 34.4%	38654. 18.2%	397. 1.0%	1378. 34.4%	1775. 4.2%	20. 3.4%	32. 18.7%	52. 6.9%
MED/DENS/RES	75625. 42.6%	13347 38.5%	88972. 41.9%	7149. 18.8%	1545. 38.5%	8694. 20.7%	339. 59.3%	96. 56.0%	435. 58.5%
LO /DENS/RES	103. .1%	5. .0%	108. .1%	3. .0%	1. .0%	4. .0%	1. .1%	0. .1%	1. .1%
HI /DENS/RES	8697. 4.9%	1968. 5.7%	10665. 5.0%	91. .2%	227. 5.7%	318. .8%	6. 1.1%	7. 4.1%	13. 1.8%
DEVELOPING	37125. 20.9%	1179. 3.4%	38304. 18.0%	29353. 77.2%	137. 3.4%	29490. 70.1%	27. 4.7%	8. 4.9%	35. 4.7%
PK/REC/PASTR	27721. 15.6%	2176. 6.3%	29897. 14.1%	1016. 2.7%	251. 6.3%	1267. 3.0%	125. 21.9%	23. 13.7%	149. 20.0%
FORESTS	0. .0%	0. .0%	0. .0%	0. .0%	0. .0%	0. .0%	47. 8.2%	0. .0%	47. 6.3%
WETLANDS	1382. .8%	0. .0%	1382. .7%	21. .1%	0. .0%	21. .0%	7. 1.3%	0. .0%	7. 1.0%
WATER	0. .0%	2766. 8.0%	2766. 1.3%	0. .0%	320. 8.0%	320. .8%	0. .0%	1. .4%	1. .1%
FREEWAYS	0. .0%	55. .2%	55. .0%	0. .0%	6. .1%	6. .0%	0. .0%	0. .2%	0. .0%
TOTALS	177685.	34645.	212330.	38031.	4009.	42040.	572.	171.	744.

Table I-A-29. Water (m^3) and sediment (kg) loadings estimated by LANDRUN for each land use in Subwatershed 6D (area in ha)--Summer 1977

LAND USE	WATER PERV	WATER IMPER	WATER TOTAL	SEDIMENT PERV	DUST/DIRT IMPER	SEDIMENT TOTAL	AREA PERV	AREA IMPER	AREA TOTAL
INDUSTRIAL	6017. 4.6%	3214. 17.0%	9231. 6.1%	53. .2%	372. 17.0%	425. 1.6%	26. 4.5%	9. 8.9%	34. 5.1%
COMMERCIAL	3458. 2.6%	1136. 6.0%	4594. 3.1%	42. .2%	131. 6.0%	173. .6%	3. .6%	3. 3.2%	6. 1.0%
MED/DENS/RES	54739. 41.7%	8563. 45.2%	63302. 42.1%	4558. 18.3%	991. 45.2%	5549. 20.4%	291. 50.8%	61. 63.2%	352. 52.6%
LO /DENS/RES	377. .3%	16. .1%	393. .3%	14. .1%	2. .1%	16. .1%	2. .4%	0. .4%	3. .4%
HI /DENS/RES	1928. 1.5%	741. 3.9%	2669. 1.8%	45. .2%	86. 3.9%	131. .5%	6. 1.1%	3. 2.7%	9. 1.3%
DEVELOPING	31113. 23.7%	859. 4.5%	31972. 21.3%	19117. 76.6%	99. 4.5%	19216. 70.8%	27. 4.7%	6. 6.3%	33. 4.9%
PK/REC/PASTR	25376. 19.3%	1317. 6.9%	26693. 17.8%	898. 3.6%	153. 7.0%	1051. 3.9%	145. 25.3%	14. 14.6%	159. 23.8%
FORESTS	0. .0%	0. .0%	0. .0%	0. .0%	0. .0%	0. .0%	30. 5.2%	0. .0%	30. 4.4%
WETLANDS	8220. 6.3%	0. .0%	8220. 5.5%	231. .9%	0. .0%	231. .9%	42. 7.4%	0. .0%	42. 6.3%
WATER	0. .0%	3114. 16.4%	3114. 2.1%	0. .0%	360. 16.4%	360. 1.3%	0. .0%	1. .7%	1. .1%
TOTALS	131228.	18960.	150188.	24958.	2194.	27152.	572.	97.	669.

Table I-A-30. Water (m^3) and sediment (kg) loadings estimated by LANDRUN for each land use in Subwatershed 6E (area in ha)--Summer 1977

LAND USE	WATER PERV	WATER IMPER	WATER TOTAL	SEDIMENT PERV	DUST/DIRT IMPER	SEDIMENT TOTAL	AREA PERV	AREA IMPER	AREA TOTAL
COMMERCIAL	18906. 8.8%	24834. 47.6%	43740. 16.3%	316. 1.1%	2874. 47.6%	3190. 9.4%	14. 1.8%	67. 31.9%	81. 8.3%
MED/DENS/RES	77686. 36.0%	13700. 26.3%	91386. 34.1%	5257. 19.0%	1585. 26.3%	6842. 20.3%	337. 44.1%	98. 46.9%	435. 44.7%
LO /DENS/RES	370. .2%	10. .0%	380. .1%	7. .0%	1. .0%	8. .0%	3. .4%	0. .1%	3. .3%
DEVELOPING	63025. 29.2%	1913. 3.7%	64938. 24.3%	18735. 67.6%	222. 3.7%	18957. 56.1%	43. 5.7%	14. 6.5%	57. 5.8%
ROW CROPS	2276. 1.1%	0. .0%	2276. .8%	1498. 5.4%	0. .0%	1498. 4.4%	29. 3.8%	0. .0%	29. 3.0%
PK/REC/PASTR	44663. 20.7%	2651. 5.1%	47314. 17.7%	1605. 5.8%	306. 5.1%	1911. 5.7%	221. 29.0%	29. 13.6%	250. 25.7%
FORESTS	0. .0%	0. .0%	0. .0%	0. .0%	0. .0%	0. .0%	72. 9.5%	0. .0%	72. 7.4%
WETLANDS	8682. 4.0%	0. .0%	8682. 3.2%	311. 1.1%	0. .0%	311. .9%	44. 5.8%	0. .0%	44. 4.5%
WATER	0. .0%	9063. 17.4%	9063. 3.4%	0. .0%	1049. 17.4%	1049. 3.1%	0. .0%	2. .9%	2. .2%
TOTALS	215608.	52171.	267779.	27729.	6037.	33766.	765.	209.	974.

Table I-A-31. Water (m^3) and sediment (kg) loadings estimated by LANDRUN for each land use in Subwatershed 6F (area in ha)--Summer 1977

LAND USE	WATER PERV	WATER IMPER	WATER TOTAL	SEDIMENT PERV	DUST/DIRT IMPER	SEDIMENT TOTAL	AREA PERV	AREA IMPER	AREA TOTAL
INDUSTRIAL	65. .1%	288. 5.3%	353. .7%	0. .0%	33. 5.2%	33. 1.3%	0. .0%	1. 2.7%	1. .3%
COMMERCIAL	7721. 16.3%	2603. 47.7%	10324. 19.5%	88. 4.6%	301. 47.7%	389. 15.3%	6. 2.1%	7. 24.3%	13. 4.3%
MED/DENS/RES	11322. 23.9%	1814. 33.2%	13136. 24.8%	641. 33.5%	210. 33.3%	851. 33.4%	59. 22.4%	13. 45.1%	72. 24.7%
LO /DENS/RES	140. .3%	3. .1%	143. .3%	2. .1%	0. .0%	2. .1%	1. .3%	0. .2%	1. .3%
DEVELOPING	346. .7%	10. .2%	356. .7%	95. 5.0%	1. .2%	96. 3.8%	0. .1%	0. .2%	0. .1%
PK/REC/PASTR	22125. 46.6%	739. 13.5%	22864. 43.2%	902. 47.1%	86. 13.6%	988. 38.8%	138. 52.3%	8. 27.5%	146. 49.9%
FORESTS	0. .0%	0. .0%	0. .0%	0. .0%	0. .0%	0. .0%	29. 11.1%	0. .0%	29. 10.0%
WETLANDS	5749. 12.1%	0. .0%	5749. 10.9%	186. 9.7%	0. .0%	186. 7.3%	31. 11.6%	0. .0%	31. 10.5%
TOTALS	47468.	5457.	52925.	1914.	631.	2545.	265.	29.	294.

Table I-A-32. Water (m^3) and sediment (kg) loadings estimated by LANDRUN for each land use in Subwatershed 4A (area in ha)--Summer 1977

LAND USE	WATER PERV	WATER IMPER	WATER TOTAL	SEDIMENT PERV	DUST/DIRT IMPER	SEDIMENT TOTAL	AREA PERV	AREA IMPER	AREA TOTAL
INDUSTRIAL	1698. 2.2%	74106. 8.9%	75804. 8.4%	159. .7%	8768. 8.9%	8927. 7.4%	1. .5%	20. 7.3%	22. 4.0%
COMMERCIAL	5816. 7.6%	118811. 14.3%	124627. 13.8%	1619. 7.0%	14057. 14.3%	15676. 13.0%	29. 10.8%	32. 11.6%	61. 11.2%
MED/DENS/RES	33928. 44.4%	337468. 40.8%	371396. 41.1%	14453. 62.8%	39926. 40.8%	54379. 44.9%	132. 49.3%	122. 44.1%	254. 46.6%
HI /DENS/RES	4150. 5.4%	57191. 6.9%	61341. 6.8%	847. 3.7%	6766. 6.9%	7613. 6.3%	12. 4.3%	18. 6.4%	29. 5.4%
DEVELOPING	1160. 1.5%	837. .1%	1997. .2%	2110. 9.2%	99. .1%	2209. 1.8%	1. .2%	1. .2%	1. .2%
PK/REC/PASTR	29654. 38.8%	63670. 7.7%	93324. 10.3%	3821. 16.6%	7533. 7.7%	11354. 9.4%	93. 34.8%	46. 16.6%	139. 25.5%
WATER	0. .0%	752. .1%	752. .1%	0. .0%	89. .1%	89. .1%	0. .0%	0. .1%	0. .0%
FREEWAYS	0. .0%	175253. 21.2%	175253. 19.4%	0. .0%	20735. 21.2%	20735. 17.1%	0. .0%	38. 13.7%	38. 7.0%
TOTALS	76406.	828088.	904494.	23009.	97973.	120982.	267.	277.	545.

Table I-A-33. Water (m^3) and sediment (kg) loadings estimated by LANDRUN for each land use in Subwatershed 4B (area in ha)--Summer 1977

LAND USE	WATER PERV	WATER IMPER	WATER TOTAL	SEDIMENT PERV	DUST/DIRT IMPER	SEDIMENT TOTAL	AREA PERV	AREA IMPER	AREA TOTAL
INDUSTRIAL	1491. 1.4%	64054. 6.1%	65545. 5.7%	134. .3%	7578. 6.1%	7712. 4.4%	1. .3%	17. 4.8%	19. 2.5%
COMMERCIAL	9433. 9.1%	221850. 21.0%	231283. 20.0%	1238. 2.5%	26248. 21.0%	27486. 15.7%	8. 2.0%	60. 16.6%	68. 9.1%
MED/DENS/RES	69784. 67.5%	679667. 64.4%	749451. 64.7%	37991. 75.5%	80413. 64.4%	118404. 67.6%	276. 70.8%	246. 67.9%	522. 69.4%
LO /DENS/RES	21. .0%	30. .0%	51. .0%	1. .0%	4. .0%	5. .0%	0. .0%	0. .0%	0. .0%
HI /DENS/RES	2381. 2.3%	34448. 3.3%	36829. 3.2%	450. .9%	4076. 3.3%	4526. 2.6%	7. 1.8%	11. 2.9%	18. 2.3%
DEVELOPING	3300. 3.2%	2374. .2%	5674. .5%	8345. 16.6%	281. .2%	8626. 4.9%	2. .5%	1. .4%	3. .4%
PK/REC/PASTR	16963. 16.4%	30326. 2.9%	47289. 4.1%	2165. 4.3%	3588. 2.9%	5753. 3.3%	96. 24.6%	22. 6.1%	118. 15.6%
WATER	0. .0%	9353. .9%	9353. .8%	0. .0%	1107. .9%	1107. .6%	0. .0%	2. .6%	2. .3%
FREEWAYS	0. .0%	12817. 1.2%	12817. 1.1%	0. .0%	1516. 1.2%	1516. .9%	0. .0%	3. .8%	3. .4%
TOTALS	103373.	1054919.	1158292.	50324.	124811.	175135.	390.	363.	752.

Table I-A-34. Water (m^3) and sediment (kg) loadings estimated by LANDRUN for each land use in Subwatershed 4C (area in ha)--Summer 1977

LAND USE	WATER PERV	WATER IMPER	WATER TOTAL	SEDIMENT PERV	DUST/DIRT IMPER	SEDIMENT TOTAL	AREA PERV	AREA IMPER	AREA TOTAL
INDUSTRIAL	28. .0%	1447. .1%	1475. .1%	4. .0%	154. .1%	158. .0%	0. .0%	0. .1%	0. .1%
COMMERCIAL	3310. 3.4%	101502. 10.2%	104812. 9.6%	1093. .5%	10815. 10.2%	11908. 3.7%	11. 3.2%	28. 7.7%	39. 5.5%
MED/DENS/RES	54152. 55.2%	680729. 68.5%	734881. 67.3%	53313. 24.5%	72529. 68.5%	125842. 38.9%	223. 65.6%	254. 69.0%	476. 67.3%
HI /DENS/RES	9673. 9.9%	158747. 16.0%	168420. 15.4%	4248. 1.9%	16914. 16.0%	21162. 6.5%	27. 8.1%	51. 13.8%	78. 11.0%
DEVELOPING	21676. 22.1%	15006. 1.5%	36682. 3.4%	157641. 72.3%	1599. 1.5%	159240. 49.2%	8. 2.5%	10. 2.6%	18. 2.5%
PK/REC/PASTR	9314. 9.5%	32360. 3.3%	41674. 3.8%	1657. .8%	3448. 3.3%	5105. 1.6%	70. 20.7%	24. 6.6%	95. 13.4%
WATER	0. .0%	4436. .4%	4436. .4%	0. .0%	473. .4%	473. .1%	0. .0%	1. .3%	1. .1%
TOTALS	98153.	994227.	1092380.	217956.	105932.	323888.	340.	368.	707.

Table I-A-35. Water (m^3) and sediment (kg) loadings estimated by LANDRUN for each land use in Subwatershed 4D (area in ha)--Summer 1977

LAND USE	WATER PERV	WATER IMPER	WATER TOTAL	SEDIMENT PERV	DUST/DIRT IMPER	SEDIMENT TOTAL	AREA PERV	AREA IMPER	AREA TOTAL
COMMERCIAL	2556. 2.7%	108888. 15.4%	111444. 13.9%	1088. .3%	11602. 15.4%	12690. 2.8%	21. 3.8%	30. 11.9%	51. 6.4%
MED/DENS/RES	25229. 26.3%	361725. 51.1%	386954. 48.1%	31430. 8.1%	38541. 51.1%	69971. 15.2%	255. 47.0%	135. 52.6%	390. 48.8%
LO /DENS/RES	50. .1%	48. .0%	98. .0%	22. .0%	5. .0%	27. .0%	0. .1%	0. .0%	0. .1%
HI /DENS/RES	3735. 3.9%	76399. 10.8%	80134. 10.0%	1743. .5%	8140. 10.8%	9883. 2.1%	16. 3.0%	24. 9.5%	41. 5.1%
DEVELOPING	37596. 39.2%	23520. 3.3%	61116. 7.6%	343049. 88.9%	2506. 3.3%	345555. 74.9%	26. 4.9%	15. 5.9%	41. 5.2%
ROW CROPS	0. .0%	0. .0%	0. .0%	0. .0%	0. .0%	0. .0%	15. 2.8%	0. .0%	15. 1.9%
PK/REC/PASTR	23121. 24.1%	40190. 5.7%	63311. 7.9%	8163. 2.1%	4282. 5.7%	12445. 2.7%	173. 31.9%	30. 11.7%	203. 25.4%
FORESTS	54. .1%	0. .0%	54. .0%	45. .0%	0. .0%	45. .0%	14. 2.5%	0. .0%	14. 1.7%
WETLANDS	516. .5%	0. .0%	516. .1%	113. .0%	0. .0%	113. .0%	9. 1.6%	0. .0%	9. 1.1%
LANDFILL	2970. 3.1%	0. .0%	2970. .4%	332. .1%	0. .0%	332. .1%	13. 2.4%	0. .0%	13. 1.6%
WATER	0. .0%	2145. .3%	2145. .3%	0. .0%	229. .3%	229. .0%	0. .0%	0. .2%	0. .1%
FREEWAYS	0. .0%	95117. 13.4%	95117. 11.8%	0. .0%	10134. 13.4%	10134. 2.2%	0. .0%	21. 8.3%	21. 2.7%
TOTALS	95827.	708032.	803859.	385985.	75439.	461424.	542.	256.	799.

Table I-A-36. Water (m^3) and sediment (kg) loadings estimated by LANDRUN for each land use in Subwatershed 3A (area in ha)--Summer 1977

LAND USE	WATER PERV	WATER IMPER	WATER TOTAL	SEDIMENT PERV	DUST/DIRT IMPER	SEDIMENT TOTAL	AREA PERV	AREA IMPER	AREA TOTAL
INDUSTRIAL	95. .1%	4357. .7%	4452. .6%	5. .0%	515. .7%	520. .4%	0. .0%	1. .5%	1. .2%
COMMERCIAL	5206. 4.6%	89686. 15.4%	94892. 13.6%	1023. 2.1%	10611. 15.4%	11634. 9.9%	6. 2.1%	24. 10.1%	30. 5.8%
MED/DENS/RES	28878. 25.3%	279175. 47.9%	308053. 44.2%	12363. 25.5%	33030. 47.9%	45393. 38.7%	119. 41.5%	101. 42.1%	220. 41.8%
HI /DENS/RES	3633. 3.2%	41919. 7.2%	45552. 6.5%	3392. 7.0%	4959. 7.2%	8351. 7.1%	8. 2.9%	13. 5.4%	21. 4.1%
DEVELOPING	348. .3%	250. .0%	598. .1%	612. 1.3%	30. .0%	642. .5%	0. .1%	0. .1%	0. .1%
ROW CROPS	444. .4%	0. .0%	444. .1%	5015. 10.3%	0. .0%	5015. 4.3%	8. 2.7%	0. .0%	8. 1.5%
PK/REC/PASTR	75725. 66.2%	126602. 21.7%	202327. 29.0%	26053. 53.8%	14978. 21.7%	41031. 34.9%	134. 46.3%	92. 38.1%	226. 42.8%
FORESTS	0. .0%	0. .0%	0. .0%	0. .0%	0. .0%	0. .0%	11. 3.9%	0. .0%	11. 2.1%
LANDFILL	14. .0%	0. .0%	14. .0%	0. .0%	0. .0%	0. .0%	0. .0%	0. .0%	0. .0%
WATER	0. .0%	40730. 7.0%	40730. 5.8%	0. .0%	4819. 7.0%	4819. 4.1%	0. .0%	9. 3.7%	9. 1.7%
FREEWAYS	0. .0%	230. .0%	230. .0%	0. .0%	27. .0%	27. .0%	0. .0%	0. .0%	0. .0%
TOTALS	114343.	582949.	697292.	48463.	68969.	117432.	286.	240.	527.

Table I-A-37. Water (m^3) and sediment (kg) loadings estimated by LANDRUN for each land use in Subwatershed 3B (area in ha)--Summer 1977

LAND USE	WATER PERV	WATER IMPER	WATER TOTAL	SEDIMENT PERV	DUST/DIRT IMPER	SEDIMENT TOTAL	AREA PERV	AREA IMPER	AREA TOTAL
INDUSTRIAL	1849. 1.2%	39057. 2.9%	40906. 2.7%	157. .1%	4519. 2.9%	4676. 1.7%	1. .3%	10. 2.2%	12. 1.3%
COMMERCIAL	4542. 3.0%	144870. 10.8%	149412. 10.0%	748. .6%	16764. 10.8%	17512. 6.3%	4. .8%	39. 8.2%	43. 4.5%
MED/DENS/RES	103569. 69.4%	959344. 71.5%	1062913. 71.3%	100494. 81.4%	111011. 71.5%	211505. 75.8%	305. 65.5%	344. 72.5%	649. 69.0%
LO /DENS/RES	11. .0%	10. .0%	21. .0%	1. .0%	1. .0%	2. .0%	0. .0%	0. .0%	0. .0%
HI /DENS/RES	7072. 4.7%	99972. 7.4%	107044. 7.2%	1952. 1.6%	11568. 7.4%	13520. 4.8%	17. 3.6%	31. 6.5%	47. 5.0%
DEVELOPING	3940. 2.6%	2809. .2%	6749. .5%	10443. 8.5%	325. .2%	10768. 3.9%	1. .3%	2. .4%	3. .3%
PK/REC/PASTR	28171. 18.9%	55442. 4.1%	83613. 5.6%	9713. 7.9%	6415. 4.1%	16128. 5.8%	137. 29.5%	40. 8.4%	177. 18.8%
WATER	0. .0%	31053. 2.3%	31053. 2.1%	0. .0%	3593. 2.3%	3593. 1.3%	0. .0%	7. 1.4%	7. .7%
FREEWAYS	0. .0%	9972. .7%	9972. .7%	0. .0%	1154. .7%	1154. .4%	0. .0%	2. .5%	2. .2%
TOTALS	149154.	1342529.	1491683.	123508.	155350.	278858.	466.	475.	940.

Table I-A-38. Water (m^3) and sediment (kg) loadings estimated by LANDRUN for each land use in Subwatershed 3C (area in ha)--Summer 1977

LAND USE	WATER PERV	WATER IMPER	WATER TOTAL	SEDIMENT PERV	DUST/DIRT IMPER	SEDIMENT TOTAL	AREA PERV	AREA IMPER	AREA TOTAL
COMMERCIAL	5463. 16.7%	149847. 44.0%	155310. 41.6%	1481. 3.6%	17340. 44.0%	18821. 23.5%	4. 3.5%	40. 38.5%	45. 19.8%
MED/DENS/RES	6632. 20.3%	58368. 17.1%	65000. 17.4%	8824. 21.6%	6754. 17.1%	15578. 19.4%	31. 26.1%	21. 20.0%	52. 23.3%
HI /DENS/RES	5665. 17.3%	47413. 13.9%	53078. 14.2%	1939. 4.7%	5486. 13.9%	7425. 9.3%	4. 3.6%	15. 13.9%	19. 8.4%
DEVELOPING	2044. 6.3%	1301. .4%	3345. .9%	22458. 55.0%	150. .4%	22608. 28.2%	1. .9%	1. .8%	2. .8%
PK/REC/PASTR	12858. 39.4%	18833. 5.5%	31691. 8.5%	6123. 15.0%	2179. 5.5%	8302. 10.3%	74. 61.2%	14. 12.9%	87. 38.7%
FORESTS	0. .0%	0. .0%	0. .0%	0. .0%	0. .0%	0. .0%	6. 4.7%	0. .0%	6. 2.5%
WATER	0. .0%	18301. 5.4%	18301. 4.9%	0. .0%	2118. 5.4%	2118. 2.6%	0. .0%	4. 3.8%	4. 1.8%
FREEWAYS	0. .0%	46396. 13.6%	46396. 12.4%	0. .0%	5369. 13.6%	5369. 6.7%	0. .0%	11. 10.1%	11. 4.7%
TOTALS	32662.	340459.	373121.	40825.	39396.	80221.	120.	105.	225.

Table I-A-39. Water (m^3) and sediment (kg) loadings estimated by LANDRUN for each land use in Subwatershed 3D (area in ha)--Summer 1977

LAND USE	WATER PERV	WATER IMPER	WATER TOTAL	SEDIMENT PERV	DUST/DIRT IMPER	SEDIMENT TOTAL	AREA PERV	AREA IMPER	AREA TOTAL
INDUSTRIAL	7830. 10.5%	147027. 31.0%	154857. 28.2%	804. 1.9%	17656. 31.0%	18460. 18.4%	6. 1.9%	84. 27.3%	89. 14.8%
COMMERCIAL	38359. 51.7%	210840. 44.5%	249199. 45.4%	6172. 14.2%	25319. 44.5%	31491. 31.4%	28. 9.2%	120. 39.1%	147. 24.4%
MED/DENS/RES	12366. 16.7%	69639. 14.7%	82005. 15.0%	6867. 15.8%	8363. 14.7%	15230. 15.2%	102. 34.1%	53. 17.2%	155. 25.6%
LO /DENS/RES	23. .0%	11. .0%	34. .0%	1. .0%	1. .0%	2. .0%	0. .0%	0. .0%	0. .0%
HI /DENS/RES	1175. 1.6%	2470. .5%	3645. .7%	159. .4%	297. .5%	456. .5%	1. .4%	2. .5%	3. .5%
DEVELOPING	9876. 13.3%	2633. .6%	12509. 2.3%	29206. 67.2%	316. .6%	29522. 29.4%	6. 1.9%	3. 1.0%	9. 1.4%
PK/REC/PASTR	4383. 5.9%	19262. 4.1%	23645. 4.3%	246. .6%	2313. 4.1%	2559. 2.5%	149. 49.9%	29. 9.5%	178. 29.5%
FORESTS	0. .0%	0. .0%	0. .0%	0. .0%	0. .0%	0. .0%	7. 2.3%	0. .0%	7. 1.1%
LANDFILL	218. .3%	0. .0%	218. .0%	2. .0%	0. .0%	2. .0%	1. .3%	0. .0%	1. .1%
WATER	0. .0%	16760. 3.5%	16760. 3.1%	0. .0%	2013. 3.5%	2013. 2.0%	0. .0%	4. 1.2%	4. .6%
FREEWAYS	0. .0%	5454. 1.2%	5454. 1.0%	0. .0%	655. 1.2%	655. .7%	0. .0%	12. 4.0%	12. 2.1%
TOTALS	74230.	474096.	548326.	43457.	56933.	100390.	298.	306.	605.

Table I-A-40. Water (m^3) and sediment (kg) loadings estimated by LANDRUN for each land use in Subwatershed 3E (area in ha)--Summer 1977

LAND USE	WATER PERV	WATER IMPER	WATER TOTAL	SEDIMENT PERV	DUST/DIRT IMPER	SEDIMENT TOTAL	AREA PERV	AREA IMPER	AREA TOTAL
INDUSTRIAL	2069. 21.4%	58748. 16.0%	60817. 16.1%	217. 3.5%	7055. 16.0%	7272. 14.5%	1. 1.1%	17. 15.9%	18. 7.9%
COMMERCIAL	4828. 49.8%	175151. 47.7%	179979. 47.8%	1121. 18.0%	21033. 47.7%	22154. 44.0%	28. 22.8%	50. 47.3%	78. 34.0%
MED/DENS/RES	855. 8.8%	24561. 6.7%	25416. 6.7%	214. 3.4%	2950. 6.7%	3164. 6.3%	17. 13.3%	9. 8.4%	26. 11.2%
HI /DENS/RES	428. 4.4%	13638. 3.7%	14066. 3.7%	161. 2.6%	1638. 3.7%	1799. 3.6%	4. 3.2%	4. 4.2%	8. 3.7%
DEVELOPING	1017. 10.5%	565. .2%	1582. .4%	4510. 72.2%	68. .2%	4578. 9.1%	1. .5%	0. .4%	1. .4%
PK/REC/PASTR	151. 1.6%	4501. 1.2%	4652. 1.2%	10. .2%	541. 1.2%	551. 1.1%	72. 57.5%	3. 3.2%	75. 32.6%
FORESTS	0. .0%	0. .0%	0. .0%	0. .0%	0. .0%	0. .0%	1. .5%	0. .0%	1. .3%
LANDFILL	341. 3.5%	0. .0%	341. .1%	12. .2%	0. .0%	12. .0%	1. 1.0%	0. .0%	1. .6%
WATER	0. .0%	13654. 3.7%	13654. 3.6%	0. .0%	1640. 3.7%	1640. 3.3%	0. .0%	3. 2.9%	3. 1.3%
FREEWAYS	0. .0%	76097. 20.7%	76097. 20.2%	0. .0%	9138. 20.7%	9138. 18.2%	0. .0%	16. 17.3%	16. 7.3%
TOTALS	9689.	366915.	376604.	6245.	44063.	50308.	124.	105.	[illegible]

Table I-A-41. Water (m³) and sediment (kg) loadings estimated by LANDRUN for each land use in Subwatershed IF (area in ha)-- Summer 1977

LAND USE	WATER PERV	WATER IMPER	WATER TOTAL	SEDIMENT PERV	DUST/DIRT IMPER	SEDIMENT TOTAL	AREA PERV	AREA IMPER	AREA TOTAL
INDUSTRIAL	1184. 2.5%	49650. 7.5%	50834. 7.2%	183. .1%	5962. 7.5%	6145. 2.1%	1. .3%	14. 6.1%	15. 3.0%
COMMERCIAL	4284. 9.2%	195991. 29.8%	200275. 28.4%	2050. 1.0%	23536. 29.8%	25586. 8.9%	30. 11.4%	56. 24.2%	86. 17.3%
MED/DENS/RES	14920. 32.1%	218233. 33.2%	233153. 33.1%	18049. 8.4%	26207. 33.2%	44256. 15.0%	75. 28.1%	83. 35.9%	157. 31.8%
LO /DENS/RES	1. .0%	60. .0%	61. .0%	2. .0%	7. .0%	9. .0%	0. .1%	0. .0%	0. .1%
HI /DENS/RES	7639. 16.4%	95226. 14.5%	102865. 14.6%	3213. 1.5%	11435. 14.5%	14648. 4.9%	14. 5.4%	31. 13.4%	45. 9.1%
DEVELOPING	13459. 28.9%	8355. 1.3%	21814. 3.1%	191532. 88.7%	1003. 1.3%	192535. 65.3%	6. 2.4%	5. 2.4%	12. 2.4%
ROW CROPS	0. .0%	0. .0%	0. .0%	0. .0%	0. .0%	0. .0%	3. 1.1%	0. .0%	3. .6%
PK/REC/PASTR	5017. 10.8%	37841. 5.8%	42858. 6.1%	934. .4%	4544. 5.8%	5478. 1.9%	136. 51.2%	29. 12.5%	165. 33.2%
WATER	0. .0%	13523. 2.1%	13523. 1.9%	0. .0%	1624. 2.1%	1624. .5%	0. .0%	3. 1.3%	3. .6%
FREEWAYS	0. .0%	39161. 6.0%	39161. 5.6%	0. .0%	4703. 6.0%	4703. 1.6%	0. .0%	9. 4.1%	9. 1.9%
TOTALS	46504.	658040.	704544.	215963.	79021.	294984.	265.	230.	495.

Table I-A-42. Water (m³) and sediment (kg) loadings estimated by LANDRUN for each land use in Subwatershed VI (area in ha)-- Summer 1977

LAND USE	WATER PERV	WATER IMPER	WATER TOTAL	SEDIMENT PERV	DUST/DIRT IMPER	SEDIMENT TOTAL	AREA PERV	AREA IMPER	AREA TOTAL
INDUSTRIAL	12. .2%	922. 1.3%	934. 1.2%	1. .1%	111. 1.3%	112. 1.2%	0. .0%	0. .9%	0. .2%
COMMERCIAL	573. 10.5%	31559. 45.0%	32132. 42.5%	466. 39.6%	3790. 45.0%	4256. 44.3%	111. 93.2%	18. 55.9%	129. 85.3%
MED/DENS/RES	2852. 52.4%	21678. 30.9%	24530. 32.4%	555. 47.2%	2603. 30.9%	3158. 32.9%	5. 4.1%	8. 25.5%	13. 8.6%
HI /DENS/RES	1668. 30.6%	14933. 21.3%	16601. 22.0%	144. 12.2%	1793. 21.3%	1937. 20.2%	2. 1.6%	5. 15.1%	7. 4.6%
PK/REC/PASTR	338. 6.2%	1075. 1.5%	1413. 1.9%	11. .9%	129. 1.5%	140. 1.5%	1. 1.2%	1. 2.5%	2. 1.5%
TOTALS	5443.	70167.	75610.	1177.	8426.	9603.	119.	32.	151.

Table I-A-43. Water (m^3) and sediment (kg) loadings estimated by LANDRUN for each land use in Subwatershed 3B (area in ha)--Summer 1977

LAND USE	WATER PERV	WATER IMPER	WATER TOTAL	SEDIMENT PERV	DUST/DIRT IMPER	SEDIMENT TOTAL	AREA PERV	AREA IMPER	AREA TOTAL
INDUSTRIAL	10322. 15.9%	149535. 17.5%	159857. 17.4%	1068. .6%	17955. 17.5%	19023. 6.4%	10. 2.8%	42. 14.0%	52. 8.1%
COMMERCIAL	18402. 28.4%	272042. 31.9%	290444. 31.6%	5227. 2.7%	32669. 31.9%	37896. 12.8%	18. 5.4%	77. 25.5%	95. 14.9%
MED/DENS/RES	8748. 13.5%	242300. 28.4%	251048. 27.3%	6042. 3.1%	29088. 28.4%	35130. 11.9%	113. 33.5%	92. 30.3%	205. 31.9%
HI /DENS/RES	2395. 3.7%	53684. 6.3%	56079. 6.1%	746. .4%	6446. 6.3%	7192. 2.4%	11. 3.2%	17. 5.6%	28. 4.4%
DEVELOPING	12800. 19.7%	7902. .9%	20702. 2.3%	177402. 91.9%	949. .9%	178351. 60.3%	6. 1.9%	5. 1.7%	11. 1.8%
PR/REC/PASTR	12170. 18.8%	74870. 8.8%	87040. 9.5%	2626. 1.4%	8993. 8.8%	11619. 3.9%	180. 53.3%	57. 18.7%	237. 36.9%
WATER	0. .0%	20609. 2.4%	20609. 2.2%	0. .0%	2475. 2.4%	2475. .8%	0. .0%	5. 1.5%	5. .7%
FREEWAYS	0. .0%	32451. 3.8%	32451. 3.5%	0. .0%	3897. 3.8%	3897. 1.3%	0. .0%	8. 2.6%	8. 1.2%
TOTALS	64837.	853402.	918239.	193109.	102482.	295591.	338.	303.	642.

Table I-A-44. Water (m^3) and sediment (kg) loadings estimated by LANDRUN for each land use in Subwatershed 1 (area in ha)--Summer 1977

LAND USE	WATER PERV	WATER IMPER	WATER TOTAL	SEDIMENT PERV	DUST/DIRT IMPER	SEDIMENT TOTAL	AREA PERV	AREA IMPER	AREA TOTAL
COMMERCIAL	646. 2.0%	33039. 12.3%	33685. 11.2%	56. .4%	3919. 12.3%	3975. 8.4%	1. 1.3%	9. 9.3%	10. 5.9%
MED/DENS/RES	24204. 74.4%	224904. 83.8%	249108. 82.8%	7802. 49.5%	26574. 83.8%	34376. 72.2%	70. 89.9%	81. 84.1%	152. 86.7%
HI /DENS/RES	115. .4%	1579. .6%	1694. .6%	6. .1%	187. .6%	193. .4%	0. .4%	0. .1%	1. .4%
DEVELOPING	4412. 13.6%	3117. 1.2%	7529. 2.5%	7902. 50.1%	386. 1.2%	8288. 17.4%	2. 2.2%	2. 2.3%	3. 2.3%
PR/REC/PASTR	2851. 8.8%	5674. 2.1%	8525. 2.8%	107. .7%	664. 2.1%	771. 1.6%	5. 5.9%	4. 4.2%	9. 5.1%
TOTALS	32520.	268252.	300782.	15773.	31730.	47611.	78.	97.	175.

Table I-A-45. Water (m^3) and sediment (kg) loadings estimated by LANDRUN for each land use in Subwatershed 2 (area in ha)--Summer 1977

LAND USE	WATER PERV	WATER IMPER	WATER TOTAL	SEDIMENT PERV	DUST/DIRT IMPER	SEDIMENT TOTAL	AREA PERV	AREA IMPER	AREA TOTAL
INDUSTRIAL	11. .0%	234. .1%	245. .1%	0. .0%	28. .1%	28. .1%	0. .0%	0. .1%	0. .0%
COMMERCIAL	2545. 7.5%	39918. 13.9%	42463. 13.2%	180. 2.3%	4723. 13.9%	4903. 11.7%	2. 2.7%	11. 10.6%	13. 7.2%
MED/DENS/RES	26433. 77.6%	225880. 78.7%	252313. 78.6%	6915. 87.7%	26724. 78.7%	33639. 80.4%	58. 72.3%	82. 80.0%	139. 76.6%
HI /DENS/RES	1069. 3.1%	13224. 4.6%	14293. 4.5%	105. 1.3%	1565. 4.6%	1670. 4.0%	2. 2.3%	4. 4.0%	6. 3.3%
DEVELOPING	481. 1.4%	334. .1%	815. .3%	430. 5.5%	40. .1%	470. 1.1%	0. .2%	0. .2%	0. .2%
PK/REC/PASTR	3536. 10.4%	7257. 2.5%	10793. 3.4%	259. 3.3%	859. 2.5%	1118. 2.7%	18. 22.5%	5. 5.1%	23. 12.7%
TOTALS	34075.	286847.	320922.	7889.	33939.	41828.	80.	102.	182.

Table I-A-46. Water (m^3) and sediment (kg) loadings estimated by LANDRUN for each land use in Subwatershed 1A (area in ha)--Summer 1977

LAND USE	WATER PERV	WATER IMPER	WATER TOTAL	SEDIMENT PERV	DUST/DIRT IMPER	SEDIMENT TOTAL	AREA PERV	AREA IMPER	AREA TOTAL
INDUSTRIAL	14695. 9.1%	680223. 26.1%	694918. 25.1%	2122. 4.4%	80479. 26.1%	82601. 23.2%	13. 3.7%	185. 23.0%	197. 17.3%
COMMERCIAL	26788. 16.6%	963993. 37.0%	990781. 35.8%	4259. 8.9%	114052. 37.0%	118311. 33.2%	23. 6.7%	262. 32.6%	285. 24.9%
MED/DENS/RES	60096. 37.3%	557160. 21.4%	617256. 22.3%	23628. 49.2%	65919. 21.4%	89547. 25.1%	173. 50.8%	202. 25.1%	375. 32.8%
LO /DENS/RES	252. .2%	306. .0%	558. .0%	15. .0%	36. .0%	51. .0%	0. .1%	0. .0%	1. .1%
HI /DENS/RES	4203. 2.6%	55930. 2.1%	60133. 2.2%	685. 1.4%	6617. 2.1%	7302. 2.0%	9. 2.7%	17. 2.2%	27. 2.3%
DEVELOPING	713. .4%	505. .0%	1218. .0%	1147. 2.4%	60. .0%	1207. .3%	0. .1%	0. .0%	1. .0%
PK/REC/PASTR	54411. 33.8%	114714. 4.4%	169125. 6.1%	16195. 33.7%	13572. 4.4%	29767. 8.3%	122. 35.9%	83. 10.4%	205. 18.0%
WATER	0. .0%	44208. 1.7%	44208. 1.6%	0. .0%	5230. 1.7%	5230. 1.5%	0. .0%	10. 1.2%	10. .8%
FREEWAYS	0. .0%	190488. 7.3%	190488. 6.9%	0. .0%	22537. 7.3%	22537. 6.3%	0. .0%	44. 5.4%	44. 3.8%
TOTALS	161158.	2607527.	2768685.	48051.	308502.	356553.	340.	803.	1143.

Table I-A-47. Water (m^3) and sediment (kg) loadings estimated by LANDRUN for each land use in Subwatershed 18 (area in ha)--Summer 1977

LAND USE	WATER PERV	WATER IMPER	WATER TOTAL	SEDIMENT PERV	DUST/DIRT IMPER	SEDIMENT TOTAL	AREA PERV	AREA IMPER	AREA TOTAL
INDUSTRIAL	2386. 4.0%	111205. 15.0%	113591. 14.2%	222. 1.3%	13157. 15.0%	13379. 12.8%	2. 1.3%	30. 13.2%	32. 8.3%
COMMERCIAL	10073. 16.9%	200742. 27.1%	210815. 26.3%	1540. 9.3%	23750. 27.1%	25290. 24.2%	15. 9.3%	55. 23.9%	69. 17.9%
MED/DENS/RES	29273. 49.2%	252247. 34.0%	281520. 35.2%	7811. 47.0%	29844. 34.0%	37655. 36.1%	65. 40.8%	91. 40.0%	157. 40.3%
HI /DENS/RES	3551. 6.0%	46094. 6.2%	49645. 6.2%	527. 3.2%	5454. 6.2%	5981. 5.7%	7. 4.5%	14. 6.3%	22. 5.5%
DEVELOPING	1368. 2.3%	949. .1%	2317. .3%	2204. 13.3%	112. .1%	2316. 2.2%	0. .2%	1. .3%	1. .2%
PK/REC/PASTR	9553. 16.0%	15742. 2.1%	25295. 3.2%	3362. 20.2%	1863. 2.1%	5225. 5.0%	58. 36.0%	11. 5.0%	69. 17.8%
LANDFILL	3354. 5.6%	0. .0%	3354. .4%	965. 5.8%	0. .0%	965. .9%	13. 7.9%	0. .0%	13. 3.2%
WATER	0. .0%	13422. 1.8%	13422. 1.7%	0. .0%	1588. 1.8%	1588. 1.5%	0. .0%	3. 1.3%	3. .8%
FREEWAYS	0. .0%	100814. 13.6%	100814. 12.6%	0. .0%	11928. 13.6%	11928. 11.4%	0. .0%	23. 10.1%	23. 5.9%
TOTALS	59558.	741215.	800773.	16631.	87696.	104327.	160.	228.	389.

Table I-A-48. Water (m^3) and sediment (kg) loadings estimated by LANDRUN for each land use in Subwatershed 19 (area in ha)--Summer 1977

LAND USE	WATER PERV	WATER IMPER	WATER TOTAL	SEDIMENT PERV	DUST/DIRT IMPER	SEDIMENT TOTAL	AREA PERV	AREA IMPER	AREA TOTAL
INDUSTRIAL	1176. 2.3%	52664. 10.5%	53840. 9.8%	91. .4%	6231. 10.5%	6322. 7.6%	1. .7%	14. 8.4%	15. 5.0%
COMMERCIAL	7026. 13.8%	114516. 22.9%	121542. 22.1%	680. 2.8%	13549. 22.9%	14229. 17.1%	7. 4.9%	31. 18.4%	38. 12.4%
MED/DENS/RES	30675. 60.1%	288972. 57.8%	319647. 58.0%	10718. 44.4%	34189. 57.8%	44907. 53.9%	93. 68.6%	105. 61.7%	197. 64.6%
HI /DENS/RES	1139. 2.2%	15529. 3.1%	16668. 3.0%	142. .6%	1837. 3.1%	1979. 2.4%	3. 2.0%	5. 2.8%	8. 2.5%
DEVELOPING	4316. 8.5%	3046. .6%	7362. 1.3%	10771. 44.6%	360. .6%	11131. 13.4%	1. 1.1%	2. 1.1%	3. 1.1%
PK/REC/PASTR	6389. 12.5%	14238. 2.8%	20627. 3.7%	1695. 7.0%	1685. 2.8%	3380. 4.1%	30. 21.8%	10. 6.1%	40. 13.1%
LANDFILL	292. .6%	0. .0%	292. .1%	45. .2%	0. .0%	45. .1%	1. .8%	0. .0%	1. .4%
WATER	0. .0%	11225. 2.2%	11225. 2.0%	0. .0%	1328. 2.2%	1328. 1.6%	0. .0%	2. 1.4%	2. .8%
TOTALS	51013.	500190.	551203.	24142.	59179.	83321.	135.	170.	305.

PART II

MODEL ENHANCED UNIT LOADING (MEUL) - A METHOD OF ASSESSING POLLUTANT LOADINGS FROM A SINGLE LAND USE

by

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ABSTRACT

The Model Enhanced Unit Loading (MEUL) method utilizing the LANDRUN model has been developed to simulate potential pollutant loadings from urban and non-urban land uses. The simulations for typical land uses are evaluated as if the land uses are located on hydrologically different soils representative of standard hydrologic categories. Pollutant loadings vary considerably among land uses. Sensitivity analyses indicate that the most significant factors affecting such differences are extent of imperviousness of urban areas, portion of the impervious areas directly connected to runoff channels, depression and storage, length of dry period between rainfall, curb height for urban areas and soil type, slope and vegetative cover for pervious urban and non-urban areas. The applicability of the unit loading data obtained by the MEUL method has been tested on several well-monitored subwatersheds in the Menomonee River Watershed. The simulated unit loadings for sediment and phosphate-P are of the same order of magnitude as the measured values.

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II-1. INTRODUCTION

The International Joint Commission, through the Great Lakes Water Quality Board, established the International Reference Group on Great Lakes Pollution from Land Use Activities (PLUARG) to study and report the effects of land use on water quality and recommend remedial measures. Several pilot watersheds subjected to detailed monitoring were selected throughout the Great Lakes Basin in Canada and the United States. The Menomonee River Watershed located in the southeastern part of Wisconsin in the Milwaukee metropolitan area was one of the watersheds selected. The primary task was to establish pollutant loadings from various land uses and extrapolate these findings to the entire Great Lakes region.

The investigation discussed in this report presents an effort to develop unit loadings for typical urban and suburban land uses using a combination of modeling techniques with measured monitored data. It is true that the best information on actual loadings can be obtained only from direct field measurements. However, the applicability of such information is limited by time and location at which the data were gathered and sometimes by the sparsity of data. On the other hand, even the most effective models may fail to provide reliable results if proper calibration and verification is not guaranteed. Thus, a combination of simulated loadings using a mathematical model, calibrated and verified by extensive monitoring data and applied to several hydrologically different seasons and soils, may provide a better understanding of the variability of the loading figures, their dependence on meteorological, pedological and environmental factors and may reveal a possible impact of some remedial measures suggested for reducing pollutant impact.

Pollution from non-point or diffuse sources originates either from weathering of minerals, erosion of virgin and forest lands including residues of natural vegetation, or from artificial or semi-artificial sources. The latter sources can be related directly to human activities such as fertilizer application or use of agricultural chemicals for controlling weeds and pests, erosion of soil materials from agricultural farming areas and animal feedlots, erosion occurring in urban developments, transportation, atmospheric fallout, etc. With the gradual elimination of point sources including sewage and industrial wastewater outfalls, it is becoming obvious that a substantial portion of surface waters pollution originates from the use of land by man, i.e. from diffuse sources.

A tendency exists to relate pollutant loadings from non-point sources to type of land use. In this approach, pollution from diffuse sources is expressed simply as a value or range of unit loadings (loadings/unit area/unit time) for the land use. This approach, though justified as an initial rough approximation may lead to results which deviate markedly from measured values. *More appropriately, it is important to examine and analyze the basic* processes and factors involved in pollutant generation from diffuse sources.

The Model Enhanced Unit Loading (MEUL) analysis is a method which assesses pollutant loadings from various land uses on a directly comparative basis. The loadings are generated by a hydrologic overland pollution transport model calibrated and verified by extensive field measurements and monitoring. The loadings generated in this way are abstracted from a particular location at a particular time and reflect for a typical area mean pollutant accumulation characteristics and statistically averaged meteorological conditions subjected to certain land uses. The pollutant loadings developed in this report do not include background or natural composition of surface waters caused by its contact with geological layers, undisturbed soils and natural vegetation.

Limitations of the MEUL method include:

1. The method is intended basically for comparative assessment of loadings among various land uses.

2. The loadings are related to a few primary variables such as degree of imperviousness of the area, cleanliness of the area, soil characteristics and type of land use.

3. The meteorological inputs represent a typical average meteorological year for the Midwest (Milwaukee). The accuracy of the estimates for pervious areas was improved by considering the 10 and 90 percentile meteorological seasons selected from 30 years of weather observations in southeastern Wisconsin.

4. The pollutant accumulation rates on impervious areas represent average U.S. rates as reported by Sartor and Boyd (1).

5. The loading figures were computed for five typical urban land uses (residential, commercial, industrial, developing and parks) and five typical non-urban land uses (row crops, pastures, woodland, wetland and feedlots).

6. The loading figures are not intended to be used for estimating accurate loadings in areas where no historical or monitoring data are available.

7. No monitored pollutant loadings from pervious areas and only limited loadings from impervious areas during winter conditions in Midwestern areas are available.

II-2. CONCLUSIONS

Large amounts of pollutants are washed into surface waters from non-point sources. The factors contributing to non-point pollution from various urban and non-urban land uses have been investigated using a calibrated and verified hydrologic transport model capable of simulating overland pollutant loading and transport. The simulated seasonal loadings provide a comparison of the variability and potential danger to surface waters of typical land use activities. The model was calibrated and verified using field data from the Menomonee River Pilot Watershed Study. The simulated loadings for typical land use areas were evaluated as if the land uses were located on four hydrologically different soils representative of standard hydrologic categories. Developing urban, high density urban areas with no cleaning practices, livestock feedlots and steep-sloped crop lands yield the highest pollutant potential while parks and recreational areas, low density residential and most urban areas with good cleaning practices produce much less pollutants. The differences in pollution potential among the land uses were several orders of magnitude. Summer rains in Midwestern areas have the highest erosion potential; however, spring rains on bare soils with frozen subsurface generate the highest sediment runoff on row cropland. By sensitivity analyses, various parameters have been tested as to their effect on loadings. The most significant parameters are extent of imperviousness of urban areas, fraction of impervious areas directly connected to surface runoff, depression and interception storage, average length of the dry period preceding a rain, curb height for urban areas and soil type, slope and vegetative cover for pervious urban and non-urban areas.

Various control techniques and their impact on non-point sources pollutant generation have been discussed.

The loading diagrams which relate sediment and phosphate-P unit loadings to the most important causative factors have been developed and their applicability tested on several subwatersheds in the Menomonee River Basin. Estimated and measured loading values were of the same order of magnitude.

II-3. METHODOLOGY

Pollutant Transport Process From Non-Point Sources

Water is the primary mover of pollutants through the environment from their sources to the place of final disposal. Unlike pollutants from point sources which enter the hydrologic transport route during a late stage of the hydrologic cycle (channel or estuary flow), non-point source pollutants enter the hydrologic route during its early stage, i.e., in precipitation or by overland flow. The point where the pollutants enter the hydrologic transport process depends not only on the type and location of the source but also on the physical form in which the pollutant occurs. Gaseous, emulsified and dispersed airborne pollutants enter the water transport route following deposition on the surface by wet or dry fallout. Soluble pollutants mix with water directly. Relatively insoluble pollutants either are dispersed and picked up during rain or snowmelt events through subsequent surface runoff, or are transported by wind and subsequently redeposited. Furthermore, pollutants can be adsorbed by soil and dust particles and transported by water in the particulate phase.

It is anticipated that non-point pollutant transport processes in urban areas may be different from those in non-urban areas because:

1. Large portions of urban areas are impervious resulting in much higher hydrological activity.

2. With the exception of construction sites most of the pervious surfaces in residential or city areas are well protected by lawns and are subject to less erosion.

3. Pollutant loadings in urban areas are affected mainly by litter accumulation, dry or wet fallout and traffic while in non-urban areas most of the pollution is due to erosion of soils and soil-adsorbed pollutants.

4. Over a large period of time (season) almost all of the pollutants deposited on impervious surfaces which have not been removed by street cleaning practices, wind or decay, eventually end up in surface runoff. On the other hand, in non-urban areas soil represents an extensive pool of sediments and pollutants adsorbed by soil and their removal rate depends then on the energy of rain or runoff which liberates the soil particles and eliminates surface protection.

Pollutant Loadings and Transport From Impervious Urban Areas

Pollutant accumulation on ground surfaces in urban areas and subsequent washout by runoff represents a major pollutant contribution from non-point urban sources. Since impervious areas are almost fully hydrologically active, most of the runoff and associated pollutants in highly urbanized areas originate from these surfaces. The amount of deposited pollutants depends on various factors and inputs. The major inputs are atmospheric fallout, street litter deposition, animal and bird fecal wastes, dead vegetation, and road traffic impacts. The factors which affect the quality of street refuse washed out to surface waters include land use, population density, traffic flow and frequency, effectiveness of street cleaning, type of street surface and condition.

It has been realized that a simple unit loading value related to land use may not provide an adequate estimation. Instead, the loading values should be correlated to major causative factors which for various urban land uses can be listed as follows:

a. Percent impervious area directly connected to a channel (a function of land use or percent of imperviousness).
b. Population density (a factor related to land use).
c. Dry and wet atmospheric fallout.
d. Litter accumulation (a factor related to population density and land use).
e. Traffic density (a factor related to land use).
f. Curb height and length/unit area (factors related to land use).
g. Percent open area (a factor related to land use).
h. Average wind velocity.
i. Street cleaning practices and effectiveness.
j. Average number of dry days preceding a rain or rain intensity.
k. Depression and interception storage (a factor related to land use).

With the exception of low density residential areas, other factors such as slope, soil type, are expected to have little effect on pollutant loads from urban areas because most of the loading originates from impervious areas.

It can be seen that most--but not all--of the above listed factors are indeed related to land use. Thus, it may be possible to develop a multidimensional loading factor for various urban land uses which would be a function of:

a. Dry fallout (primary independent variable).
b. Street cleaning frequency and efficiency.) parametric
c. Average wind velocity.) independent variable
d. Average number of dry days preceding a rain.)

Unit Loadings From Pervious Areas

Urban or suburban pervious areas with the exception of those overlain with heavy clay soils or areas with a very high groundwater table are hydrologically active only during extreme storms or during spring melt or rain events when the ground is frozen. Freezing of the surface layers in Midwestern areas of the United States also provides protection against erosion and groundwater contamination.

Sediment and soil-adsorbed pollutants (e.g., P, heavy metals and most pesticides) can be modeled by the Universal Soil Loss Equation (USLE). The equation in its original form (2) can be written as:

$$A = (R)\ (K)\ (LS)\ (C)\ (P) \qquad \text{Eq. (1)}$$

where

A is amount of sediment generated/storm
R is the rainfall energy factor of the storm
K is the soil erodibility factor
LS is the length-slope factor
C is the vegetative cover factor
P is the erosion control factor

In this form the equation represents the amount of soil particles liberated by rain energy impact. In order to obtain the sediment load to receiving waters the equation must be multiplied by a delivery ratio:

$$AS = D * A \qquad \text{Eq. (2)}$$

where AS is the sediment load and D is the sediment delivery ratio.

Loadings of some pollutants other than sediment are then estimated by

$$PL = AS * CP * RP \qquad \text{Eq. (3)}$$

where

PL is pollutant loading
CP is pollutant content of the soil
RP is the enrichment factor accounting for the difference in pollutant content in soil and the sediment suspended in water

It is possible now to estimate which of the above variables is land use related.

Rainfall factor, R

This is a function of storm intensity and volume and is not related to any land use activity.

The rainfall energy factor, R, is computed according to the equation:

$$R = \Sigma_i\{[(2.29 + 1.15 \log X_i)]D_i\}I \qquad \text{Eq. (4)}$$

where

X_i is rainfall intensity, cm/hr

Σ_i is rainfall hydrograph time interval

D_i is rainfall depth during time interval i

I is the maximum 30 min rainfall intensity of the storm in cm/hr

It is evident that the rain energy input/season reduced by the amount of snowpack on the surface is the major independent variable affecting the soil loss estimation.

Soil erodibility factor, K

This is purely a function of soil characteristics (2,3). For most Midwestern soils the K factor is in the range 0.1 to 0.4.

Slope-length factor, LS

This is based on formula (2):

$$LS = L^{1/2}(0.0138 + 0.00974S + 0.001385^{2}) \qquad \text{Eq. (5)}$$

where

L is length from the point of origin of the overland flow, m

S is the average slope over the given overland flow length, %

The equation indicates that soil loss is more sensitive to slope changes than to the size of the area.

Vegetative cover factor, C

This variable depends on the crop or vegetative cover and the season. It varies from 0.005 for heavily wooded areas to 1.0 for bare soils. Besides the rain energy factor and slope this is a variable to which soil loss is very sensitive.

Erosion control practice factor, P

This factor depends on erosion practices implemented in the Watershed. In the absence of such practices the value assigned to this factor is unity.

Delivery ratio factor, D

This is probably the most difficult factor to estimate. For larger watersheds the delivery ratio seems to be a function of watershed size and configuration. For smaller areas it may be a function of the lot roughness (depression and interception storage) and, mainly, permeability. For relatively homogeneous sites, a study by the Midwest Research Institute (4) related delivery ratio to soil texture and drainage density which is defined as the ratio of total channel-segment lengths to the basin area.

If a loading function is to be developed it should be related to the rainfall energy factor as a primary independent variable, with soil type, slope and depression storage as parametric variables

Application of LANDRUN Model - Model Enhanced Unit Loading (MEUL) Simulations Based on Land Use

This method used in the study to develop loading functions relied on field data and system simulation. It has been realized that although the field data provide the best information on pollutant loadings from a particular site the information is limited by time and location at which the data were gathered. On the other hand, even the most complex simulation model of a watershed can provide results quite far from reality if the model is not properly calibrated or verified.

A model developed for this study has the code name LANDRUN (5). It is a deterministic watershed model capable of simulating the following processes:

a. Snowpack-snowmelt by the Holtan or Philip Models.
b. Infiltration by the Holtan or Philip Models.
c. Excess rain can be computed as the difference between precipitation and evaporation, evapotranspiration, infiltration and surface storage.
d. Routing of excess rain by an Instantaneous Unit Hydrograph Method.
e. Dust and dirt accumulation in urban areas and washout.
f. Removal of accumulated pollutants on impervious areas by cleaning practices.
g. Surface erosion by a modified quasi-dynamic USLE which includes effects of rainfall energy and sheet runoff.
h. Routing of the sediment and sediment-adsorbed pollutants.

The model takes into consideration several parameters including:

a. Land use data.
b. Meteorological parameters.
c. Pollutant input.

The computer model is capable of estimating:

a. Storm water hydrographs and volume.
b. Sediment transport from pervious areas.
c. Dust and dirt washout from urban impervious areas.
d. Volatile suspended solids in the runoff.
e. Adsorbed pollutant loadings.

A dynamic soil adsorption segment is an optional feature of the model which enables detailed study of pollutant-soil interactions (6).

Following calibration and verification of the LANDRUN model (7), pollutant loading simulations were conducted for the land uses agreed upon by PLUARG. The land uses were grouped into urban and non-urban categories:

Urban uses	Non-urban uses
Low density residential	Row crops
Medium density residential	Pasture
High density residential	Livestock feedlots
Commercial	Woodlands
Industrial	Wetlands
Park and recreation	
Developing	

To simulate pollutant loadings, each land use was assigned typical values for such variables as degree of imperviousness, fraction of impervious areas directly connected to a channel, depression storage, permeability of pervious areas, slope, soil moisture characteristics, etc. In addition, other variables describing atmospheric fallout, litter accumulation, street sweeping practices and the USLE inputs were selected. The values were based on Menomonee River Pilot Watershed data or on literature values typical of Midwestern urban areas.

Surface characteristics

The model requires a detailed description of the hydrologic characteristics of the subwatershed surface. Included are: Degree of imperviousness, depression and interception (surface) storage, subwatershed slope, surface roughness and extent of impervious areas directly connected to a channel.

Most of the land surface data was obtained from the SEWRPC Land Data Management System (Land DMS) (8). Unless otherwise specified default values were substituted in the model for depression and interception storage and surface roughness. For combined depression and interception storage characteristics, default values used are: 6.35 mm (1/4 inch) for pervious areas and 1.58 mm (1/16 inch) for impervious areas. These values are similar to those used in the Chicago study (9) and other urban studies. For non-urban pervious areas a graph developed by Hiemstra (10) served as a guide to selection of the storage characteristics (Fig. II-1).

Surface roughness characteristics are necessary if routing of pollutants is required. The value of the Manning roughness factor for pervious areas is 0.25 and for impervious areas is 0.012.

The impervious areas not directly connected to the surface runoff channels include rooftops discharging through underground drains, paved areas overflowing on adjacent pervious surfaces, etc. This factor can be related approximately to the total imperviousness of the area as shown in Fig. II-2. The simulated areas were 1 km^2 for each land use.

Soils

For simulation purposes, four soils typical of the Menomonee River Watershed or immediate vicinity were selected. These soils are representative of each basic hydrologic group ranging from the most permeable hydrologic group A to the least permeable group D (11).

Table II-1 shows the basic soil data used in the simulation; these data reflect typical values for soils given in SCS soil maps. More exactly measured values for ten major soil types in the Donges Bay Road subwatershed (station 463001) are reported in Table II-2.

Some of the data such as 0.3-bar moisture tension (field moisture capacity) and 15-bar moisture tension (wilting coefficient) are unavailable from soil maps. In this case, a graph relating moisture characteristics to median particle diameter of the soils was prepared using data from the Menomonee River Watershed and literature values (Fig. II-3). The median particle diameter in mm was computed using a formula suggested by Horn (13):

$$d_m = \frac{1}{100} [0.3 (\% \text{ sand}) + 0.01 (\% \text{ silt}) + 0.002 (\% \text{ clay}] \qquad \text{Eq. (6)}$$

The particle sizes (Fig. II-4) are the averages of the particle size ranges recommended by the U.S. Department of Agriculture (USDA).

The permeability ranges related to soil mean particle diameter are shown in Fig. II-5. Known and measured data for some Wisconsin soils indicate that a lower range of permeability seems to be typical for Wisconsin rather than an average theoretical curve. However, data measured by Bouma et al. (14) represent permeabilities of septic tank seepage fields after several years of operation and may not provide a good approximation of permeability of typical undisturbed soils. Such values confirm the lower limits of the permeability-texture relationship.

Soil erosion data

Use of the USLE requires a knowledge of: the rainfall energy factor (R), soil erodibility factor (K), cropping management factor (C), erosion control practice factor (P) and the slope-length factor (LS).

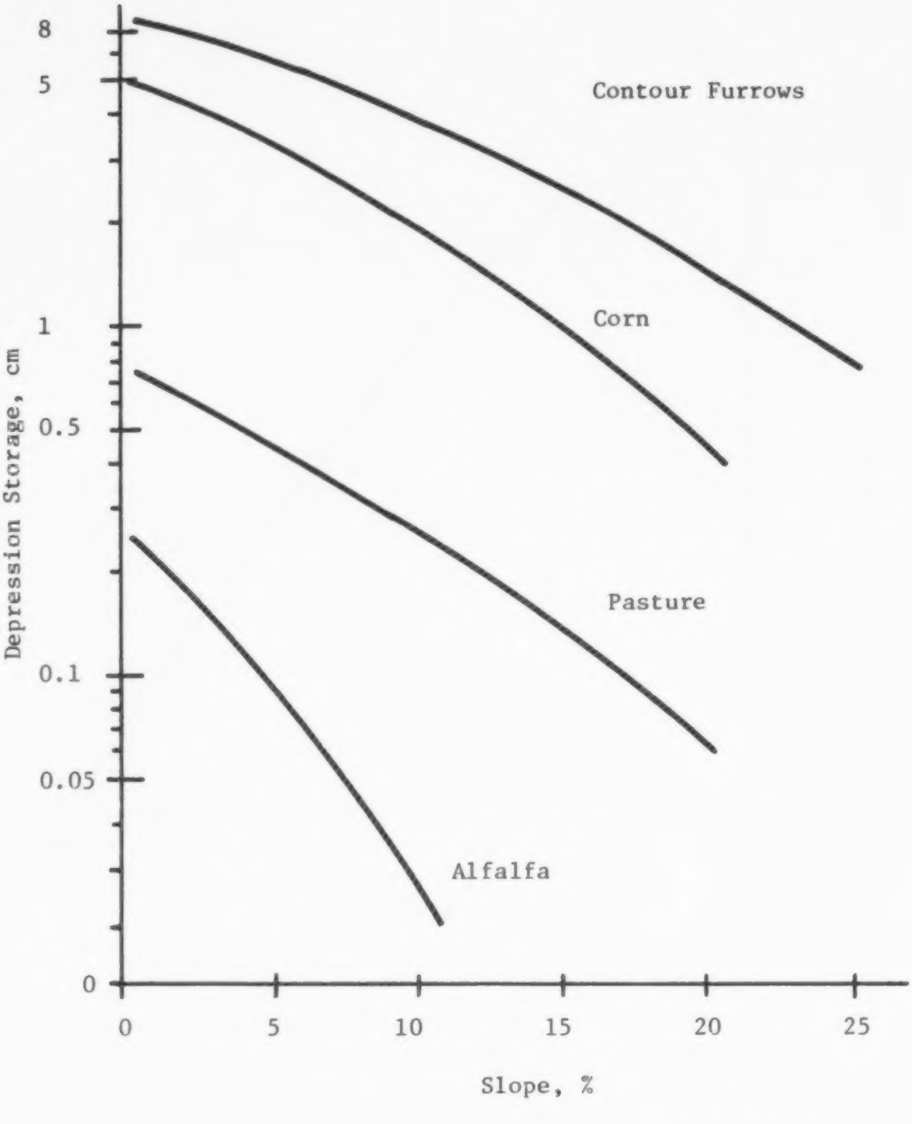

Fig. II-1. Depression storage capacity in relation to degree of land slope (10).

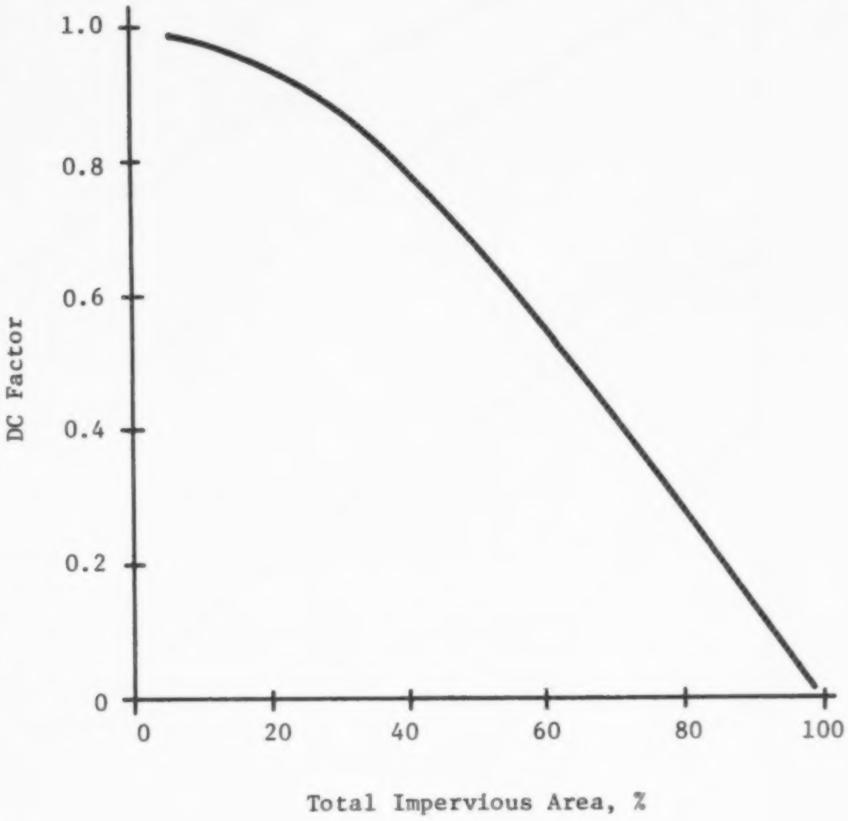

Fig. II-2. Fraction of impervious areas not directly connected to channel (12).

Table II-1. Properties of soils used in the simulation

Property	Soil type Boyer ls	 Hochheim l	 Ozaukee sil	 Ashkum sicl
Hydrologic group	A	B	C	D
Depth of A-horizon, cm	41	20	28	28
Sand, %	80	45	15	5
Silt, %	15	39	55	56
Clay, %	5	16	20	39
Mean diameter, mm	0.415	0.138	0.051	0.021
Organic matter, %	0.5	2.0	3.0	8.0
Permeability of A-horizon, cm/hr	40	10	3.0	0.5
0.3 bar H_2O content, %	8	20	30	36
15 bar H_2O content, %	0	7	17	24
Porosity, %	30	34	43	46
K factor*	0.09	0.24	0.31	0.15
PO_4-P adsorption,** ug/g	243	346	403	697
Total P content, ug/g	1,000	1,500	1,800	3,100

*K is the soil erodibility factor used in USLE.

**Soil adsorption maximum obtained from the Langmuir isotherm.

Table II-2. Properties of the major soil types surrounding the Donges Bay station (463001), Menomonee River Watershed

Property	Soil type									
	Ozaukee sil	Mequon sil	Ogden muck	Pella sil	Theresa sil	Sebewa sil	Colwood sil	Ashkum sicl	Fox l	Kibbie sil
Area, ha	1,018	182	162	101	73	47	56	50	39	31
% of total area*	47.5	8.5	7.6	4.7	3.4	2.2	2.6	2.4	1.8	1.4
Depth of A-horizon, cm	18	28	90	30	40	40	23	25	18	
Hydrologic group	C	C	D	B	D	D	D	D	B	B
pH	6.6 to 7.3	7.4 to 7.8	6.6 to 7.8	6.6 to 7.3	6.6 to 7.8	7.4 to 7.8	7.4 to 7.8	7.4 to 7.8	6.1 to 7.3	7.4 to 7.8
Clay, %	20.3 to 20.8				11.7 to 13.1			39.7		
Organic C,** %	1.52 to 1.70				3.89 to 4.30			3.66 to 5.88		
0.3 bar H_2O content, %					34.6			16.2 to 19.2		
15 bar H_2O content, %	7.8 to 8.1				10.5					
Available H_2O, cm/cm	0.20	0.20	>0.20	0.24	0.20	0.20	0.20	0.20	0.16	0.16
Extractable Fe, %	1.2 to 1.3							1.1 to 1.2		
Bulk density, g/cm^3	1.44 to 1.55				1.20 to 1.31			1.50 to 1.85		
Permeability, cm/hr	1.6 to 5.1	1.6 to 5.1	1.6 to 5.1	1.6 to 5.1	1.6 to 5.1	1.6 to 5.1	1.6 to 5.1	1.6 to 5.1	1.6 to 5.1	1.6 to 5.1
Porosity, %	41.5 to 45.7									
Cation exchange capacity, me/100 g	14.0 to 14.4				21.2 to 23.9			33.2 to 33.9		

*Total area of Donges Bay station subwatershed is 2,144 ha.
**To convert organic C to organic matter divide organic C by 0.60

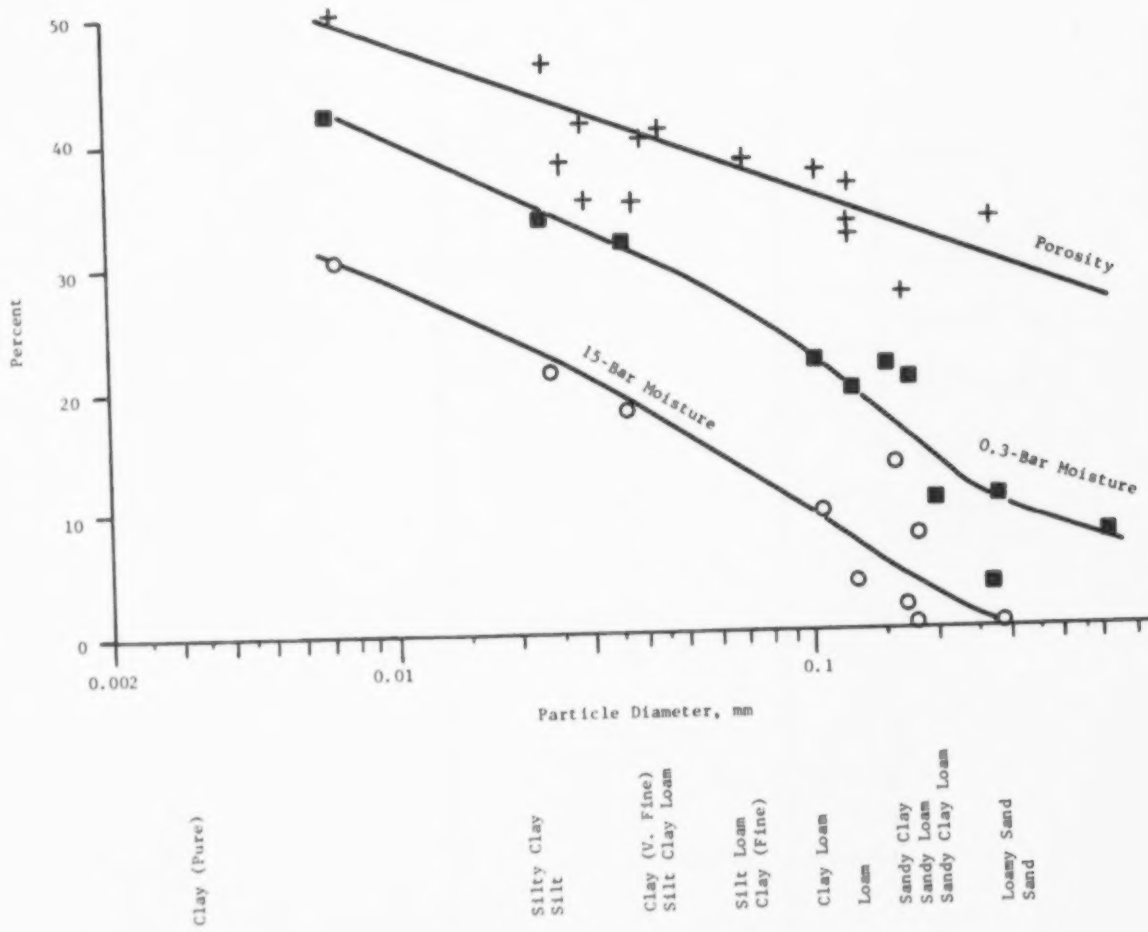

Fig. II-3. Moisture characteristics of selected soils.

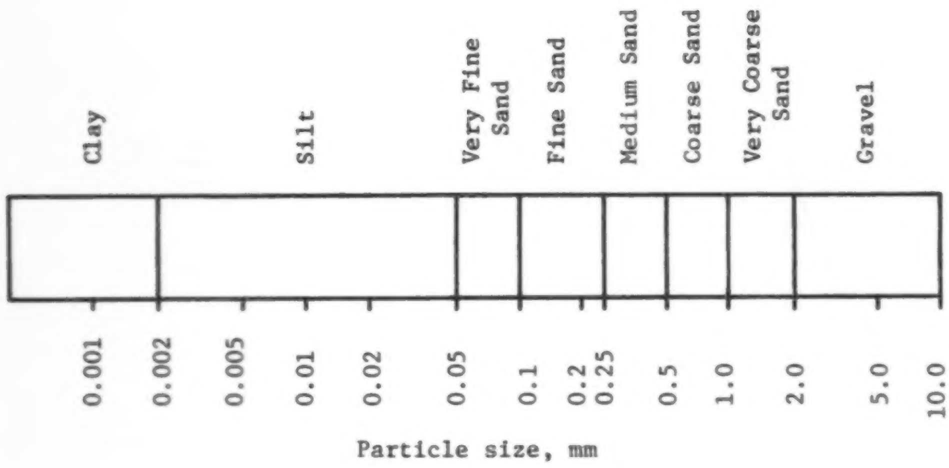
Clay
Silt
Very Fine Sand
Fine Sand
Medium Sand
Coarse Sand
Very Coarse Sand
Gravel
0.001
0.002
0.005
0.01
0.02
0.05
0.1
0.2
0.25
0.5
1.0
2.0
5.0
10.0
Particle size, mm

Fig. II-4. Soil particle size distribution accepted by USDA-SCS.

Textural Class USDA-SCS	Mean Particle Diameter, mm
Sand	0.285
Loamy Sand	0.250
Sandy Clay Loam	0.176
Sandy Loam	0.167
Sandy Clay	0.157
Loam	0.124
Clay Loam	0.103
Clay (Fine)	0.0785
Silt Loam	0.0726
Silty Clay Loam	0.0362
Clay (Very Fine)	0.0328
Silt	0.0240
Silty Clay	0.0236

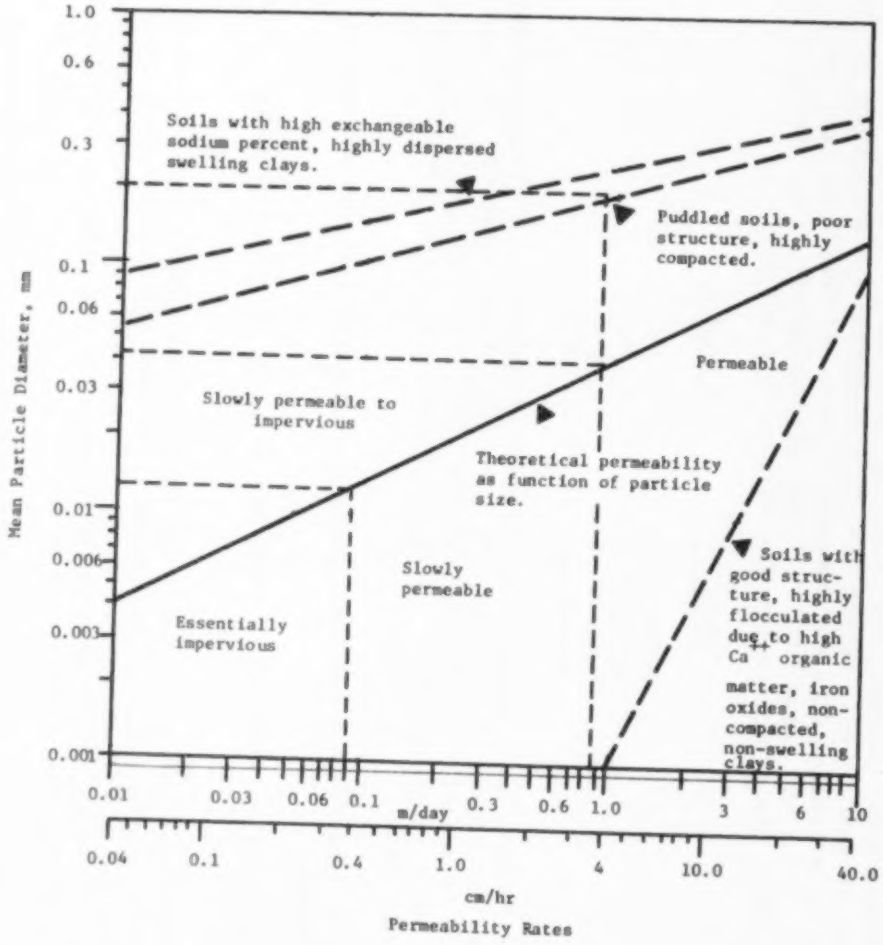

Fig. II-5. Relationship between soil permeability and soil texture (13).

The value of R is computed by the LANDRUN model from the rainfall data and the LS factor is estimated from average slope and area of the subwatershed for each land use. However, the remaining three factors must be inputted for each soil and land cover. Figure II-6 is a nomograph for estimating K. The factor K is determined from the contents of silt and very fine sand (particle size 0.01 to 0.1 mm), sand (0.1 to 2 mm), organic matter, soil structure and permeability. The K factors for the selected four soils are:

Soil	K factor
Boyer ls	0.09
Hochheim sil	0.24
Ozaukee sil	0.31
Ashkum sicl	0.15

The factor, C, is dependent on type of groundcover, general management practices and composition of the soil. For simulation purposes, the values suggested by Brandt (15) were used (Table II-3). For agricultural cultivated lands C was 1 during the spring season and adjusted to its tabular value for summer and fall.

The P factor was 1 for most land uses. Some erosion control was assumed on croplands.

Organic matter content of soils was selected to reflect typical values in the Watershed.

Phosphate-P content of soils was based on the known range of P content of the Ozaukee sil ($P = 0.18\ \%$) which was determined from the measured total P-suspended solids relationship from the spring runoff at the Donges Bay Road station. The phosphate-P content for other soils was adjusted according to their adsorption characteristics, Q^o (6).

The lead content of average soils is very low. The U.S. Geological Survey (USGS) has undertaken an in-depth study (16) to determine the elemental composition of surficial materials in the United States. Soil samples were collected from 863 sites throughout the 48 conterminous states and analyzed for 44 elements. The average values for eastern and western parts of the United States are presented in Table II-4.

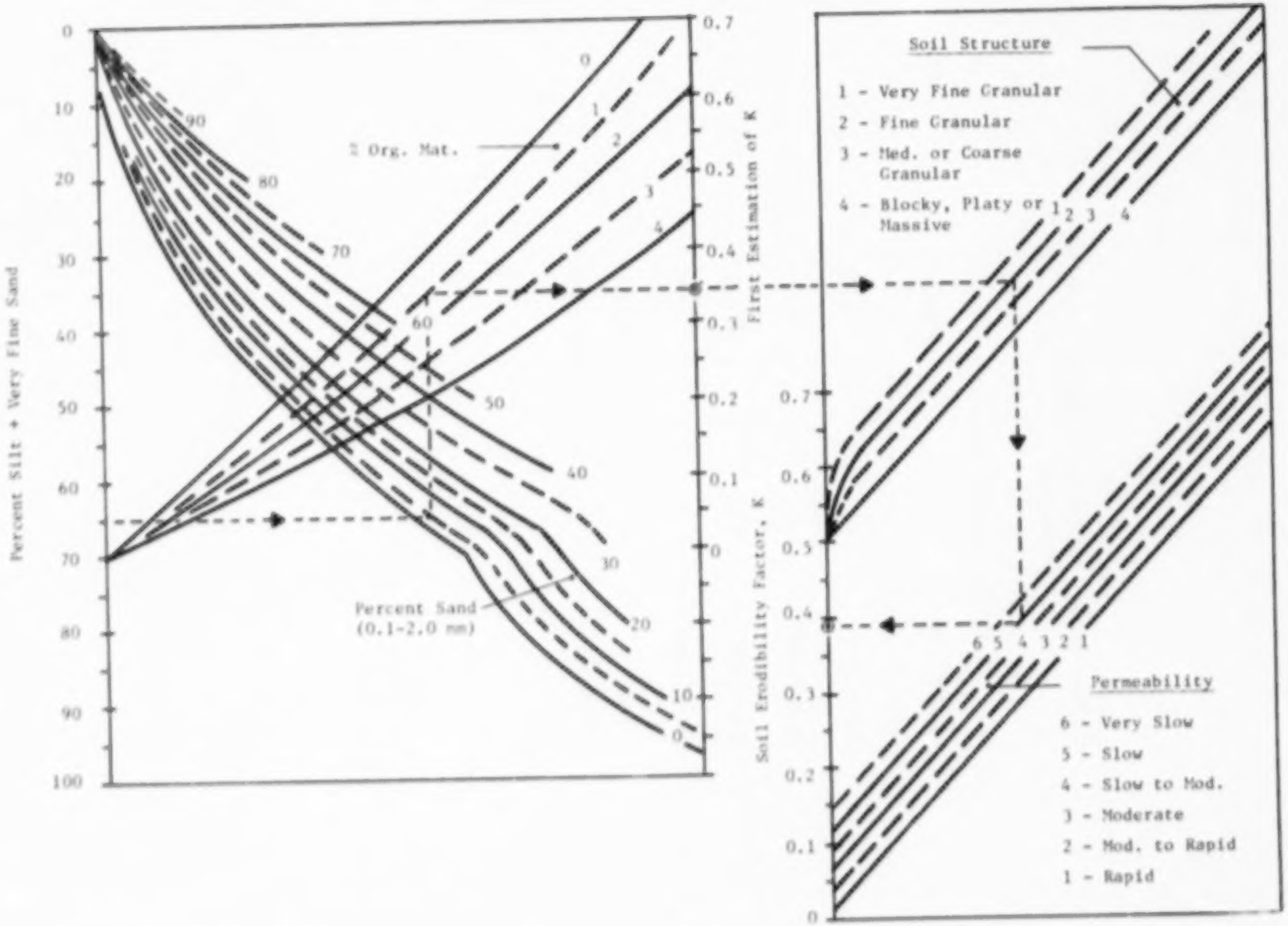

Fig. II-6. Determination of soil K factor (3).

Table II-3. C-value used to compute erosion (15)

Land use	C-value
Cropland	0.08
Grassland	0.01
Woodland	0.05
Construction	1.00
Urban	0.01

Table II-4. Metal concentrations of surficial materials of the U.S.A.(16)

Element	Average, μg/g	Range, μg/g	Geometric means, μg/g		
			Conterminous U.S.A.	West of 97th meridian	East of 97th meridian
As	--*	< 1,000	--	--	--
Ba	554	15 to 5,000	430	560	300
Cd	--	< 20	--	--	--
Ce	86	<150 to 300	75	74	78
Cr	53	1 to 1,500	37	38	36
Co	10	<3 to 70	7	8	7
Cu	25	<1 to 300	18	21	14
Fe	25,000	100 to 100,000	18,000	20,000	15,000
Ga	19	<5 to 70	14	18	10
Ge	--	< 10	--	--	--
Au	--	< 20	--	--	--
Hf	--	< 100	--	--	--
In	--	< 10	--	--	--
La	41	<30 to 200	34	35	33
Pb	20	<10 to 700	16	18	14
Mn	560	<1 to 7,000	340	389	285
Mo	3	<3 to 7	--	--	--
Nd	45	<70 to 300	39	36	44
Ni	20	<5 to 700	14	16	13
Nb	13	<10 to 100	12	11	13
Pd	--	< 1	--	--	--
Pt	--	< 30	--	--	--
Re	--	< 30	--	--	--
Sc	10	<5 to 50	8	9	7
St	240	<5 to 3,000	120	210	51
Ta	--	< 200	--	--	--
Te	--	< 2,000	--	--	--
Tl	--	< 50	--	--	--
Th	--	< 200	--	--	--
Ti	3,000	300 to 15,000	2,500	2,100	3,000
U	--	< 500	--	--	--
V	76	<7 to 500	56	66	46
Yb	4	<1 to 50	3	3	3
Y	29	<10 to 200	24	25	23
Zn	54	<25 to 2,000	44	51	36
Zr	240	<10 to 2,000	200	170	250
Total	30,100		2,990	23,858	19,263

* Below detection limit.

Pollutant accumulation in urban areas

The basic feature of urban areas is the extent of imperviousness of the land surface. Besides the hydrological significance of impervious areas (higher runoff, shorter duration of high pollutant concentrations, higher flood peaks), essentially all pollutants are flushed into the receiving waters whenever runoff takes place.

Pervious urban areas produce pollutant loadings of lesser magnitude provided that these areas are not steep and are well protected by lawns, shrubbery and trees. The amount of pollutants deposited on impervious areas depends on various factors and inputs as mentioned earlier. Pollutants transported from impervious areas can be carried by wind and traffic impact and they accumulate near the curb. Thus, it has been reported that street pollution accumulation rates are related to the unit length of curb (Fig. II-7; Table II-5). Reporting street refuse loadings/unit length of curb, instead of a more meaningful area loading, seems to be justified since it has been observed that almost 80% of refuse can be found within 15 cm and 97% within 1 m of the curb (17). The strong correlation existing between curb length density and degree of imperviousness of residential areas (Fig. II-8) can be utilized for simulation purposes.

A recently-developed regression formula (9) between curb length of urban areas and population density is:

$$CL = 311.67 - (266.07)\,(0.839)^{(2.48\ PD)} \qquad \text{Eq. (7)}$$

where

CL is curb length in m/ha
PD is population density, persons/ha

Refuse washed from streets by runoff contains many hazardous contaminants. Significant organic pollutants, toxic metals, pesticides and bacteria are associated commonly with the dust and dirt fraction (Tables II-6 and II-7). It should be noted that these values, though typical, are not uniform but represent averages from a wide range of refuse deposition and contamination from a limited number of municipalities which have been studied.

Atmospheric pollutant deposition

Deposition of atmospheric pollutants occurs as dry or wet fallout. The deposition rates of particulate atmospheric pollutants in United States cities vary from 3.5 to >35 Tonnes/km^2/month. Higher deposition rates can be expected in congested industrial areas or business districts while lower deposition rates are common in residential and rural suburban zones (Table II-8).

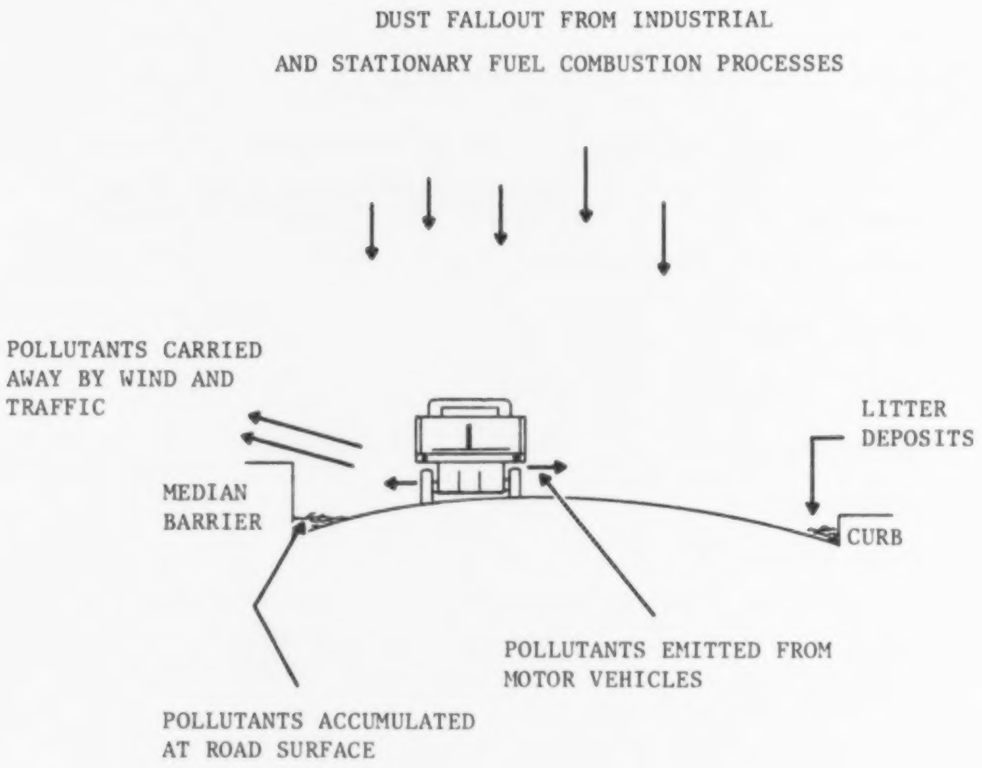
DUST FALLOUT FROM INDUSTRIAL
AND STATIONARY FUEL COMBUSTION PROCESSES
POLLUTANTS CARRIED AWAY BY WIND AND TRAFFIC
LITTER DEPOSITS
MEDIAN BARRIER
CURB
POLLUTANTS EMITTED FROM MOTOR VEHICLES
POLLUTANTS ACCUMULATED AT ROAD SURFACE

Fig. II-7. Pollutant accumulation schematic model.

Table II-5. Street refuse accumulation

Land use	Solids accumulation, g/curb m/day	
	Chicago*	Eight U.S. cities**
Single family	10.4	48
Multiple family	34.2	66
Commercial	49.1	69
Industrial	68.4	127
Weighted average	22.3	

*Taken from (9); data is for dust and dirt only.
**Taken from (1); data is for total solids which contain 75% dust and dirt.

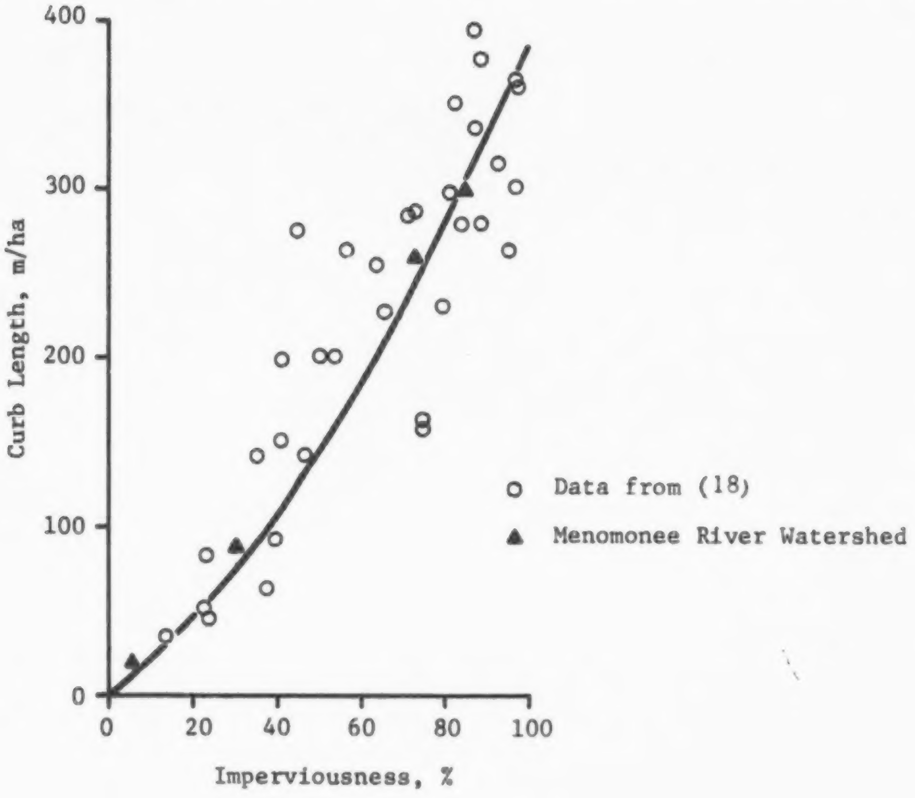

Fig. II-8. Curb length-imperviousness relationship.

Table II-6. Pollutants associated with street refuse (1)

Pollutant	Concentration, ug/g total solids			
	Residential	Industrial	Commercial	Total
BOD_5*	5,000	3,000	7,700	5,000
COD	33,800	59,000	31,500	--
Volatile solids	78,000	56,500	77,000	71,400
Total nitrogen	1,020	870	600	1,570
Nitrate-N	32	41	314	67
Phosphate-P	600	800	550	780
Total metals	2,040	1,150	1,800	--
Zn				460
Cu				140
Pb				410
Ni				36
Hg				52
Cr				78
p,p'-DDD, ng/g				48
p,p'-DDT, ng/g				43
Total coliforms, organisms/g				$71x10^6$
Fecal coliforms, organisms/g				$40x10^6$

*Taken from (9).

Table II-7. Metal contamination of street refuse (19)

Contaminant	Concentration, μg/g total solids Residential	Industrial	Commercial	Total
Cd	3.45	2.83	3.92	2.82
Cr	186	208	241	183
Cu	95	55	126	101
Ni	22	59	59	31
Pb	1,468	1,339	3,924	1,324
Sr	23	134	151	177
Zn	397	283	506	338

Table II-8. Annual and monthly mean deposition rates of particulate material in Milwaukee County (20)

Land use	Annual deposition rate, Tonnes/km^2/yr							
	1951	1957	1963	1965	1966	1967	1968	1969
Agricultural and rural suburbs	58.4	64.3	85.2	102.1	114.5	129.5	98.5	80.4
Residential	93.6	82.7	88.5	99.4	97.7	95.2	94.0	81.0
Local business	152.4	113.2	124.4	102.5	109.0	121.9	123.6	96.5
Commercial	191.3	200.0	153.7	173.8	153.7	190.4	169.6	146.5
Industrial	342.8	235.1	172.4	189.6	174.1	180.0	177.1	170.4

Monthly deposition rate (1951 to 1969), Tonnes/km^2/mo											
Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
9.85	10.4	12.9	14.1	14.5	12.8	10.5	10.6	10.6	10.2	9.71	8.09

Wind erosion

The effect of wind erosion on surface particulate pollutant loadings seems to be significant only occasionally. Factors important in the assessment are: climate, soil characteristics, surface roughness, vegetative cover and length of the eroding surface (21). In urban areas the primary source of wind eroded materials are open, ungrassed areas and construction sites.

Motor vehicles

Traffic can contribute significantly to pollutant deposition in urban areas. High amounts of some metals in storm water runoff are attributed to motor vehicle emissions and to the breakdown of road surface materials and vehicular parts. Motor vehicle usage can influence pollutant accumulation in urban areas and near high density traffic lanes by emission of pollutants, oil and gasoline spillage, mechanical impact of traffic, tire abrasion, etc. Therefore, in addition to traffic density, the pavement composition and conditions are significant in determining traffic impact on pollution. Streets paved entirely with asphalt have provided total solids loadings of about 80% higher than all-concrete streets (17). Streets where conditions were rated "fair to poor" were found to have total solids loadings ~2.5 times greater than those rated "good to excellent" (1).

Litter deposition

Litter deposits in urban areas include solid wastes dropped from garbage collectors, animal and bird fecal droppings, fallen tree leaves, grass clippings, etc. The dust and dirt component of litter (material <3.5 mm) is regarded as having greatest pollution potential; although most of the litter is orginally larger in size than dust and dirt, the mechanical fracture of litter increases the amount of dust and dirt. It has been reported that residential areas had greater amounts of street surface dust and dirt as population density increased, reflecting increased pedestrian and roadway traffic (9). It is also expected that the higher the population density, the greater the street deposition from garbage collections.

Effect of vegetation

Leaf fall and grass clippings in urban areas contribute significantly to dust and dirt accumulation. For most of the year, the accumulation on impervious areas arises from erosion of soils from surrounding pervious areas, atmospheric pollution and litter accumulation and during the fall season, leaf fall increases the organic solids accumulated at the surface.

Heaney and Huber (22) estimated from the study of Carlisle et al. (23) that average leaf fall was 14 to 26 kg/tree/year. The area investigated was stocked with trees ranging in age from 40 to 120 years with a 90 to 95% closed canopy, and 155 trees/ha; species were mainly oak and birch. Typical values for leaf fall in Minnesota are ~380 Tonnes/km^2/year in a forested area with ~420 trees/ha with 65% occurring during the fall season. Fallen leaves are 90 to 97% organic matter and contain about 0.04 to 0.28% P (24).

For loading simulations, values of leaf fall for various land uses were estimated (Table II-9). Organic and P contents of leaves were assumed to be 90 and 0.1%, respectively.

A detailed statistical evaluation of street litter accumulation is contained in Appendix II-A.

Pollutant washout

Not all pollutants accumulated during a period preceding a rainfall are washed off the impervious surface during the initial moments of the rain. The rate at which loose particulate matter is washed from street surfaces depends on three factors, namely, rainfall intensity, street surface characteristics and particle size (17). It can be expected that the amount of pollutants washed off generally will follow the equation:

$$PL = \frac{dL}{dt} = - K_p L \qquad \text{Eq. (8)}$$

where

PL is pollutant washout rate
L is amount of pollutant present on the surface
K_p is a coefficient depending on rain intensity and street surface characteristics

The coefficient, K_p, which was found to be independent of particle size in the range of 10 to 1000 μm is approximated as follows:

$$K_p = E_u R \qquad \text{Eq. (9)}$$

where

E_u is urban washout coefficient
R is the surface runoff rate, cm/hr

Table II-9. Daily leaf fall

Land use	Leaf fall, Tonnes/km^2/day Spring-Summer	 Fall
Forest	2.45	7.0
Parks	1.22	3.5
Low density residential	0.17	0.35
Medium density residential	0.08	0.18
High density residential, commercial and industrial	0.016	0.036

Values close to 1.81^{-1} have been reported for the washout coefficient, E_u (25).

Not all litter is available for transport by surface runoff. Therefore sediment washout rate should be multiplied by an availability factor (25) as:

$$A_s = 0.57 + 0.5\ R^{1.1} \qquad \text{Eq. (10)}$$

It is obvious that a limit must be placed on the availability factor as runoff rate increases. A suggested value for the maximum A_s is 0.75, which implies that about 25% of urban litter is unavailable for transport.

Street sweeping practices

Street sweeping is a common practice in American cities whereas in European cities streets are washed. Most of street sweeping is done mechanically either by brush or vacuum. Removal efficiencies with brush sweepers are shown in Table II-10; removal of deposited suspended solids is ~50% with one pass of a sweeper. Some pollutants are associated more with finer particle fractions (Table II-11). By cumulative multiplication of sweeping efficiency for each fraction and pollution concentrations on particles of the fraction, overall efficiency can be estimated (Table II-12), e.g., the efficiency of sweeping for P control would be 22% compared to 50% for total solids. Street washing is more effective for fine materials.

Meteorological inputs

The climate of the Milwaukee area is influenced by the general storms which move eastward across the upper Ohio River valley and the Great Lakes region.

Annual precipitation is about 762 mm (30 in); two-thirds of which occurs during the growing season. Thunderstorms, which carry the highest erosion potential, occur less frequently and with less severity than in areas to the south and west. The maximum rainfall which occurred in a 24-hr period is 172 mm (5.76 in) in June 1917. As much as 20 mm (0.79 in) has fallen in 5 min, 28 mm (1.11 in) in 10 min, 34 mm (1.34 in) in 15 min, 42 mm (1.86 in) in 30 min, and 57 mm (2.25 in) in 1 hr.

The average yearly rainfall energy factor, R, for sediment loss estimation by the USLE assigned for the Milwaukee area is R = 125 (2).

It has been realized that pollutant loadings shall be representative of an average season, i.e., they express loadings which would be a mathematical average over a long time period. In order to obtain such averages, at least 20 to 30 yr of data is necessary. In the absence of such a data base, as is almost always the case, water quality (loading) data time series can be generated by a properly calibrated and verified model using a measured meteorological time series as input. Hourly precipitation data for the

Table II-10. Pollutant distribution in various particle sizes (17)

Particle size, µm	Pollutant distribution, %				
	Total solids	Volatile solids	COD	TKN	PO_4-P
>2000	24.9	11.0	2.9	9.9	0
840-2400	7.6	17.4	4.5	11.6	0.9
246-840	24.6	12.0	13.0	20.0	6.9
104-246	27.8	16.1	12.4	20.2	6.4
43-104	9.7	17.9	45.0	19.6	29.6
<43	5.9	25.6	22.7	18.7	56.2

Table II-11. Interrelationship of sweeper efficiency and particle size (17)

Particle size, µm	Sweeper efficiency, %
>2000	79
840-2000	66
246-840	60
104-246	48
43-104	20
<43	50
Overall	18

Table II-12. Street sweeping removal efficiency of pollutants (17)

Pollutant	Removal efficiency, %
Total solids	50.0
Volatile solids	42.5
COD	31.0
TKN	43.9
PO_4-P	22.2

Milwaukee area are available and a time series covering 37 yr was prepared.

In an ideal case, the simulation period would cover an entire 37 yr of data, but with more complex models such simulation periods may prove to be prohibitively expensive requiring considerable computer time and storage capacity.

To avoid the expensive, long simulation runs, the 37 yr series of meteorological data was analyzed as to its distribution of seasonal wetness and erosion potential.

The wetness analysis utilized a simple summation of precipitation per calendar season; the seasonal erosion potential is based on the USLE R factor as expressed by Eq. (4). In analyzing the erosion potential, only rain events were counted, snowfall was omitted.

The probabilistic distributions of seasonal wetness and erosion potential are shown in Figs. II-9 and II-10. The arrows indicate the probabilistic expectancy of season from the monitoring period 1975-1977. It should be pointed out that the graphs are typical for the storm patterns in the Milwaukee area and should not be generalized to other areas.

Summaries of the final land data used for simulation are in Tables II-13 and II-14.

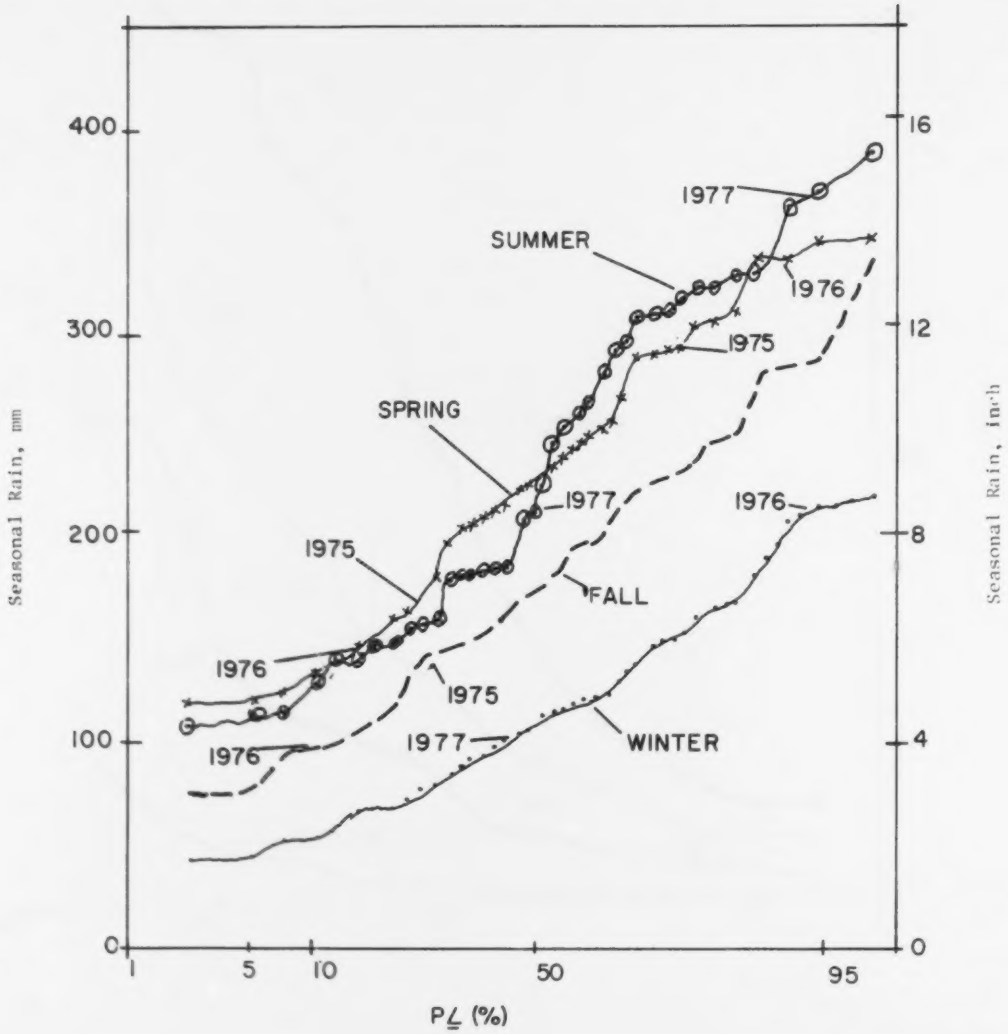

Fig. II-9. Seasonal cumulative frequency of precipitation.

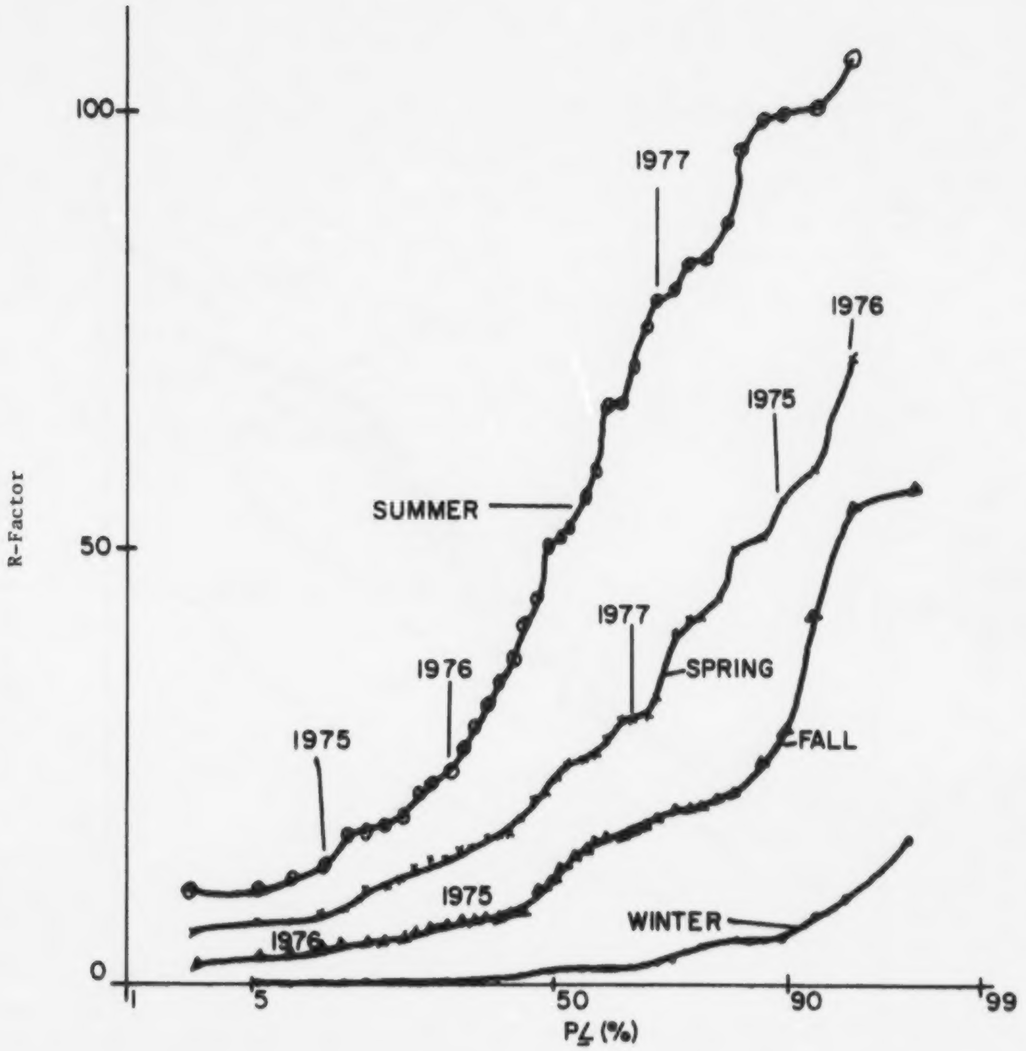

Fig. II-10. Seasonal cumulative frequency of R factor .

Table II-13. Urban land use information

Category	Land use						
	Residential						
	Low density	Medium density	High density	Commerical	Industrial	Park and recreation	Developing
Housing, dwelling/ha	0.3 to 5	5 to 16	>16				
Curb, m/ha	95	270	300	300	300		
Impervious area, %	25	60	95	90	90	2.0	3.0
Impervious area not connected, %	90	55	10	10	10	90	90
Street litter accumulation, g/m/day	45	66	60	65	100		
Dust and dirt fallout, tonnes/km^2/day							
Spring and summer	0.25	0.25	0.28	0.46	0.50	1.4**	0.5
Fall	0.6	0.5	0.3	0.48	0.5	3.5**	0.5
Sweeping frequency, days							
Well maintained	7	7	7	7	7)	30)	1000^+
Poorly maintained	1000^+	1000^+	1000^+	1000^+	1000^+)	)	
Sweeping efficiency, %							
Solids	50	50	50	50	50	50	50
PO_4-P	22	22	22	22	22	22	22
Impervious area affected by sweeping, %	50	50	50	50	50	50	50
C factor for pervious area*	0.01	0.01	0.01	0.01	0.01	0.01	0.01

*C is the cropping factor used in USLE.
**Includes leaf fall and vegetation.
+Denotes the absence of maintenance.

Table II-14. Non-urban land use information

Category	Land use				
	Row crop	Feedlots	Pasture	Wetlands	Woodlands
Impervious area, %	1.0	1.0	1.0	1.0	1.0
Litter and atmospheric fallout, tonnes/km^2/day					
Spring and summer	0.2	0.2	0.2	0.2	2.4
Fall	0.2	0.2	0.2	0.2	7.0
C factor*					
Spring	1.0	1.0	0.03	0.5	0.005
Summer and fall	0.08	1.0	0.03	0.2	0.005
P factor**	0.8	1.0	1.0	1.0	1.0
Soil	average	compacted; high organic matter and P contents	average	average; high water table	average

*C is the cropping factor in USLE.
**P is the conservation factor in USLE.

RESULTS AND DISCUSSION

Simulated Loadings

The simulation results for each land use and characteristic season produced loading diagrams which related loadings of pollutants (sediment, volatile suspended solids and phosphate-P) to the R-factor for mostly pervious areas and to atmospheric fallout for impervious areas. These loading diagrams are presented in Appendix II-B.

Loadings for urban areas were related to the degree of imperviousness and accumulation rates established for relatively clean areas (i.e., areas which are swept about once a week) and areas with on cleaning. The upper curves represent loadings from poorly-maintained areas based on a uniform daily rate of pollutant accumulation which decreases with prolonged dry periods similar to the rates reported (1,17). The loadings for urban land uses were plotted separately for impervious and pervious areas. It should be remembered that the loading from the impervious areas was estimated assuming an atmospheric fallout rate of 0.8 Tonnes/km^2/day and curb litter loadings similar to those obtained by Sartor and Boyd (1) and Sartor et al. (17). If significantly different accumulation rates are anticipated the loadings from impervious areas should be adjusted accordingly to reflect the change in curb loading rate due to increased or decreased atmospheric fallout.

Since impervious urban areas were simulated for an average year and the loadings appear to have no correlation with rainfall intensity, the average loading values can be read directly from the diagram and values are presented in Table II-15. In order to obtain average loadings for pervious areas, the loading diagram related to the R-factor must be transformed to a probability distribution loading plot using the cumulative frequency chart of the R-factor as given in Fig. II-10. The area under the R-factor-probability curve can be graphically or numerically integrated according to the equation:

$$I = \int_o^1 L_i p_i \, dp \qquad \text{Eq. (11)}$$

where

I is the average loading, kg/ha

L_i is the loading function

p_i is the assigned probability of L_i being less or equal.

It also should be noted that the loading diagrams in Appendix II-B reflect loadings from a 1 km^2 area under slope category B (2 to 6%) for the impervious urban areas and slope category C (6 to 12%) for pervious areas. To transform these values to other slopes and areal units, the loadings corresponding to pervious areas should be multiplied by slope or area

Table II-15. Simulated pollutant loadings* for urban land uses under slope category B (2 to 6%) during an average year (1968)

Soils and maintenance	Imperv., %	Sediment, kg/ha				Volatile susp. solids, kg/ha				PO_4-P, kg/ha				Pb, kg/ha			
		Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall
						Low Density Residential											
Poor soils, poorly maintained area	25	24	300	450	150	2.0	19.0	22.0	**	0.016	0.44	1.10	0.34	0.035	0.29	0.25	0.24
Poor soils, well maintained area	25	16	130	365	100	1.25	5.0	13.0	**	0.01	0.36	1.00	0.20	0.035	0.036	0.057	0.012
Permeable soils, poorly maintained area	25	24	225	240	130	2.0	15.0	13.0	**	0.016	0.15	0.18	0.12	0.23	0.29	0.25	0.24
Permeable soils, well maintained area	25	16	55	180	35	1.25	3.0	4.0	**	0.01	0.04	0.12	0.03	0.023	0.036	0.056	0.012
						Medium Density Residential											
Poorly maintained area	60	221	900	1,100	600	17	70	80	98	0.14	1.25	1.36	0.98	0.32	1.31	1.43	0.90
Well maintained area	60	141	275	540	120	11	19	34	19	0.09	1.10	1.00	0.13	0.21	0.31	0.50	0.11
						High Density Residential											
Poorly maintained area	95	294	2,090	2,040	1,700	22	180	150	498	0.20	1.62	1.44	1.50	0.43	3.40	2.98	2.80
Well maintained area	95	187	304	800	200	14	20	60	28	0.13	0.33	0.70	0.16	0.27	0.49	0.67	0.28
						Commercial											
Poorly maintained area	90	264	1,950	1,920	1,720	16	121	115	287	0.11	1.00	1.30	1.00	1.06	8.16	7.08	6.63
Well maintained area	90	167	283	516	200	10	17	28	34	0.07	0.30	0.60	0.20	0.66	1.03	1.60	0.25
						Industrial											
Poorly maintained area	90	403	2,970	2,770	2,600	29	229	201	520	0.21	2.00	2.40	2.18	0.54	4.25	3.71	3.48
Well maintained area	90	256	420	1,200	330	18	298	83	65	0.13	0.60	1.10	0.30	0.33	0.54	1.50	0.40

*Simulated loadings were obtained assuming dust fallout rates of 0.8 tonnes/km^2/day except for park and recreational areas where the value was increased to 1.4 in the Spring and to 3.5 tonnes/km^2/day in the Fall because of the effect of dead vegetation.

**60 to 85% of the total sediment was in the form of vegetation.

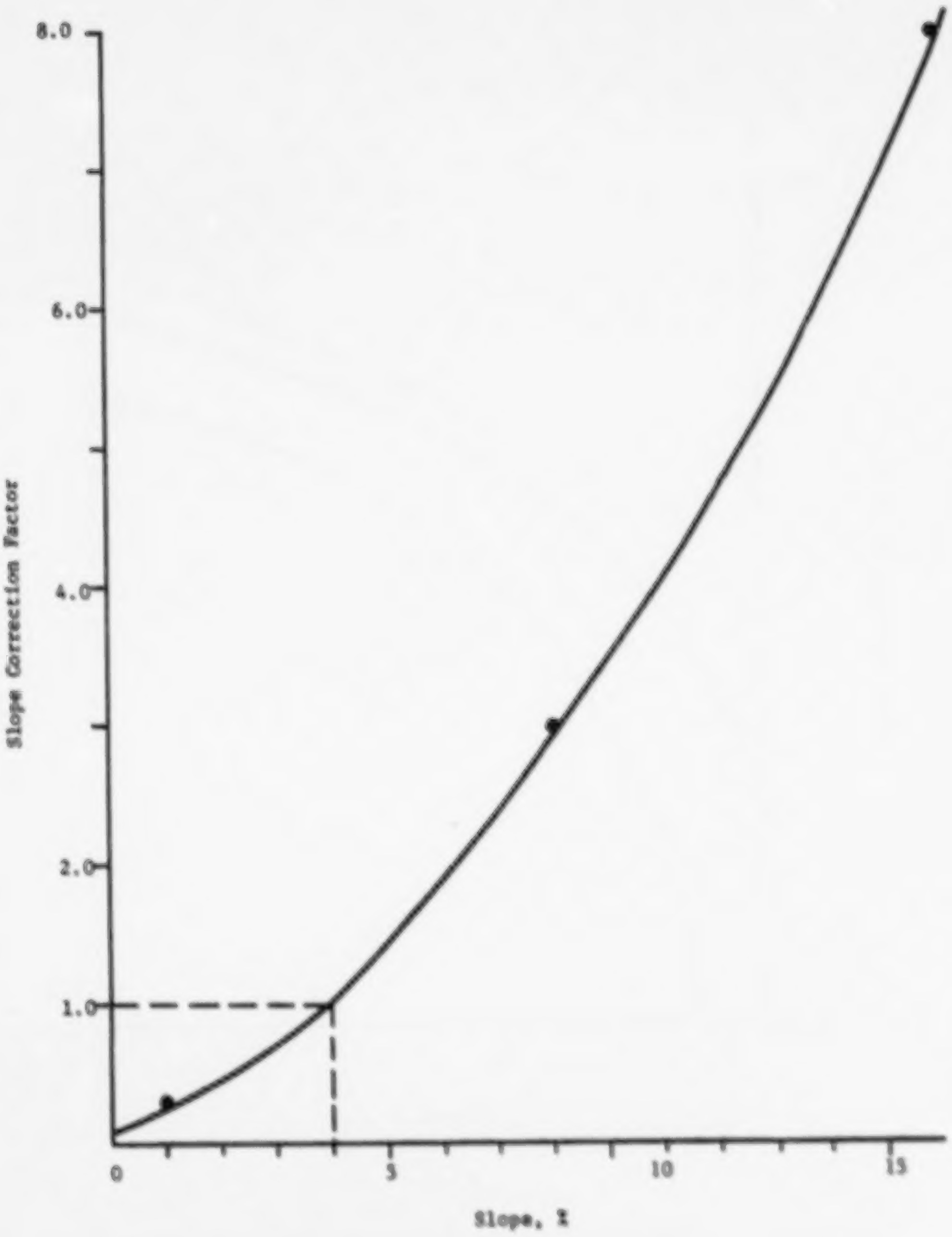

Fig. II-11. Slope correction factor for sediment and phosphate loadings from pervious urban areas (use with Table II-15).

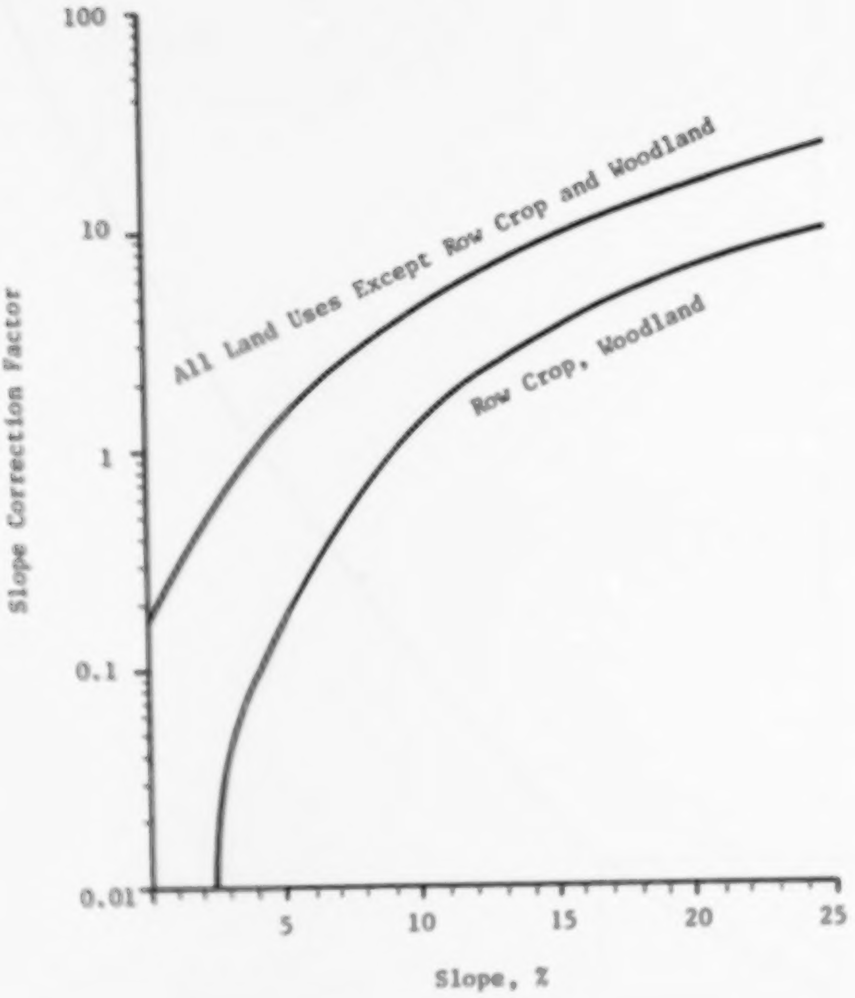

Fig. II-12. Loading multiplier for different slope categories (for use with Table II-16).

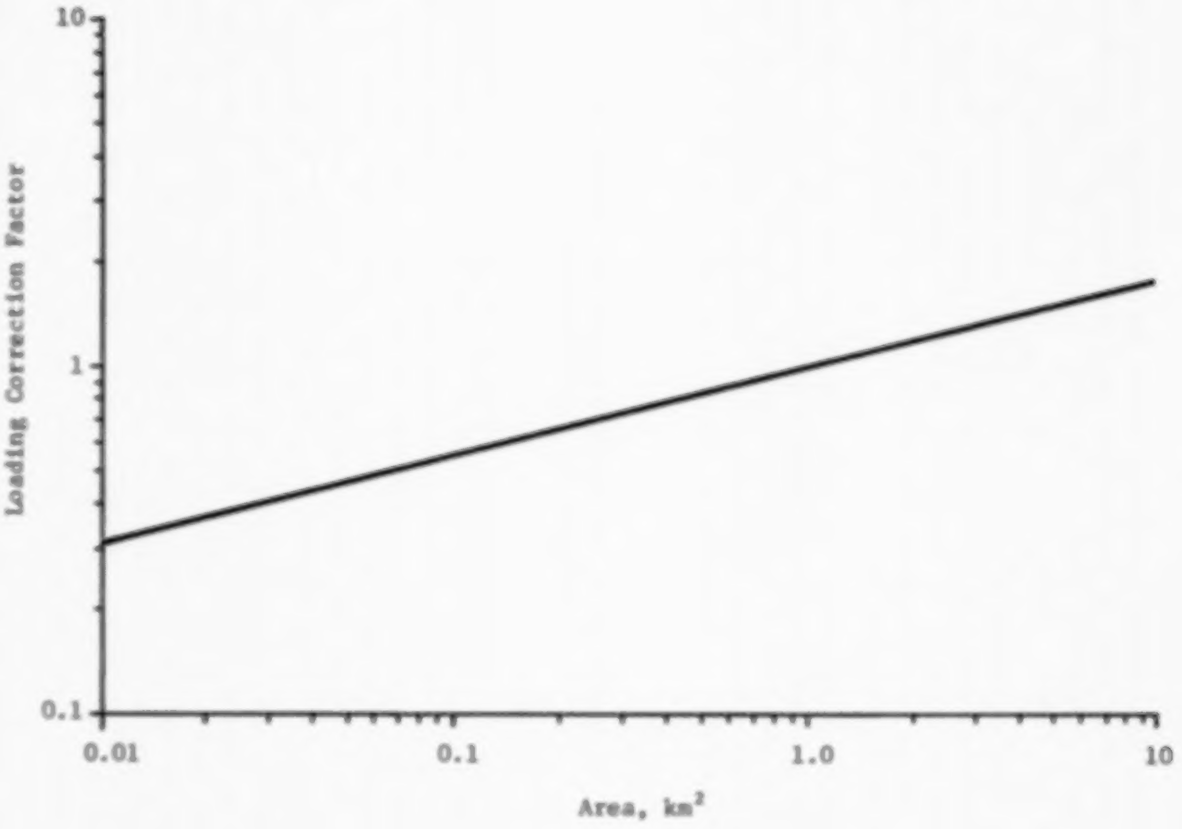

Fig. II-13. Relationship of the size of the area to sediment loading.

that erosion potential of soils in the slope category D (12 to 20%) is about 20 times greater than that for soils in slope category A (0 to 2%).

Table II-16 shows the average potential loading values for typical pervious land (non-urban) uses situated on the four hydrologic soil groups. The loadings for each land use, soil and season are long-term average simulation results.

It is seen from Tables II-15 and II-16 that developing urban, industrial, commercial and high density residential land uses with poor maintenance and street cleaning practices, produce the highest potential loadings in urban areas while low density residential and park and recreation land uses contribute the least. For non-urban land uses, livestock feedlots are expected to have the highest pollution potential and woodlands the lowest. However, simulated loadings for feedlots may be unrealistic because of the impossibility of arriving at reasonable values for the soil erodibility factor, K, due to the unusually high organic matter content and unknown compactness of feedlot soils.

Differences between the pollution potentials for various land uses indicate that pollution control measures should be concentrated intensively on hazardous land uses; i.e., developing and high density residential areas, unprotected non-urban areas located on soils with low permeability and steep slopes and feedlots. Discussion of remedial measures is given in Appendix II-C.

Comparison of Measured Loadings with Estimates Obtained by the MEUL Method

One purpose of the Menomonee River pilot project was to establish loadings from various land use activities. Although at the conclusion of the research it can be stated that the loadings should be related to various causative factors such as imperviousness of the area, type and slope of the soils, vegetative factors etc., some of these factors may indeed be related to land use. For example, the imperviousness of the area which is one of the primary factors defining residential land uses can be correlated with housing density. However, it must be realized that great loading variations should be expected within one particular land use based upon soil type and slope category, atmospheric fallout and litter accumulation and type of activities taking place in the area. This is especially true for such land uses as low density residential where most of the loadings originate from pervious areas thereby involving soil type and slope as principal causative factors. Furthermore, commercial and industrial land categories seem to be too broadly-defined and need further subcategorization (e.g., type of industry or type of commercial activities, degree of imperviousness).

Another problem which can arise when comparing estimated and measured loadings is that each season has a different erosion potential. This is shown in Fig. II-10 where cumulative rainfall energy factors defined by the USLE were arranged on a probabilistic scale of seasons. More than one order of magnitude of sediment loss can be expected based on whether the season is dry or has a significant number of high intensity storms. The measured values

Table II-16. Simulated pollutant loadings for land uses on essentially pervious areas

Soil and slope*	Sediment, kg/ha			PO_4-P			Sediment, kg/ha			PO_4-P		
	Spring	Summer	Fall	Spring	Summer	Fall	Spring	Summer	Fall	Spring	Summer	Fall
	Park and Recreation—SC† = 0.1						Pasture—SC = 0.03					
[illegible]	18	23	17	0.02	0.03	0.02	25	56	11	0.02	0.05	0.02
[illegible]	66	66	26	0.06	0.07	0.03	102	178	47	0.10	0.17	0.05
[illegible]	120	184	82	0.12	0.10	0.07	330	563	226	0.33	0.56	0.22
[illegible]	33	52	26	0.06	0.08	0.03	60	142	48	0.09	0.21	0.07
[illegible]	84	160	46	0.16	0.26	0.06	292	488	107	0.36	0.68	0.16
[illegible]	275	477	176	0.42	0.72	0.25	786	1,620	492	1.19	2.52	0.75
[illegible]	55	64	30	0.09	0.15	0.05	156	206	60	0.23	0.37	0.11
[illegible]	172	235	55	0.30	0.42	0.09	487	680	135	0.87	1.22	0.26
[illegible]	506	682	217	0.80	1.29	0.38	1,670	2,060	420	2.65	3.75	1.11
[illegible]	1,280	1,770	588	2.15	3.19	1.07	3,830	5,300	1,770	6.48	8.53	3.18
[illegible]	61	119	31	0.17	0.35	0.08	152	330	62	0.47	1.03	0.19
[illegible]	184	360	57	0.35	1.05	0.15	522	1,080	160	1.60	3.11	0.63
[illegible]	532	1,010	225	1.63	3.11	0.68	1,560	3,010	663	4.85	9.30	1.98
	Woodland—SC = 0.003						Wetland—SC = 0.03					
[illegible]	<1	<1	<1	<0.001	<0.001	<0.001	26	43	6	0.03	0.05	<0.001
[illegible]	1.5	1.8	<1	0.0015	0.001	<0.001	97	164	12	0.10	0.16	0.03
[illegible]	16	35	5.6	0.016	0.035	0.010	**	**	**	**	**	**
[illegible]	<1	<1	<1	<0.001	<0.001	<0.001	69	126	11	0.10	0.19	0.02
[illegible]	3.5	2.2	<1	0.005	0.003	<0.001	236	385	36	0.38	0.58	0.05
[illegible]	29	81	19	0.046	0.032	0.027	**	**	**	**	**	**
[illegible]	<1	<1	<1	<0.001	<0.001	<0.001	119	268	19	0.21	0.43	0.03
[illegible]	6.3	6.2	<1	0.015	0.021	<0.001	662	873	58	0.75	1.18	0.11
[illegible]	85	150	32	0.153	0.250	0.058	**	**	**	**	**	**
[illegible]	1,600	1,300	2,800	2.52	2.56	0.52	**	**	**	**	**	**
[illegible]	<1	2.9	<1	<0.001	0.019	<0.001	163	590	25	0.43	1.08	0.08
[illegible]	7.1	32	2.1	0.022	0.098	0.007	528	1,590	80	1.61	3.37	0.25
[illegible]	86	156	50	0.28	1.55	0.16	**	**	**	**	**	**
	Row Crops—SC = 1.0 or 0.08						Developing Urban—SC = 1.0					
[illegible]	<10	<10	<10	<0.01	<0.01	<0.01	830	1,800	700	0.83	1.80	0.70
[illegible]	315	18	<10	0.38	0.02	<0.01	3,600	5,900	1,600	5.40	5.90	1.60
[illegible]	2,000	560	150	2.8	0.56	0.15	11,000	18,100	7,200	13.0	18.1	7.20
[illegible]	<10	<10	<10	<0.01	<0.01	<0.01	2,000	4,700	1,800	3.00	7.05	2.40
[illegible]	675	36	<10	0.98	0.05	<0.01	8,600	15,100	3,650	12.8	25.5	5.65
[illegible]	3,500	1,280	296	6.25	1.92	0.44	26,500	47,200	16,600	39.7	71.0	24.8
[illegible]	<10	10	<10	<0.01	0.02	<0.01	4,700	6,900	2,000	8.10	12.6	3.60
[illegible]	1,665	100	<10	3.00	0.18	<0.01	16,200	23,000	4,500	29.2	41.6	8.10
[illegible]	17,000	2,600	518	30.6	4.55	0.94	49,100	68,700	20,700	88.6	125	37.5
[illegible]	200,000	20,800	4,560	515	37.5	8.20	128,000	177,000	58,000	228		106
[illegible]	<10	68	<10	<0.01	0.16	<0.01	5,100	11,000	2,100	15.8	56.1	6.51
[illegible]	1,620	505	56	4.58	1.56	0.11	17,600	33,500	6,700	56.0	106	16.8
[illegible]	18,700	3,560	600	57.8	18.9	2.50	52,200	100,000	21,500	161	311	66.7
	Feedlots—SC = 1.0											
[illegible]	976	1,650	652	1.02	2.07	0.80						
[illegible]	2,670	5,240	1,560	3.89	6.68	2.71						
[illegible]	7,200	8,750	5,630	16.6	17.6	10.9						
[illegible]	2,640	5,600	1,150	7.53	10.8	5.19						
[illegible]	6,580	7,860	5,185	18.2	25.8	10.2						
[illegible]	18,800	21,200	13,600	56.6	63.8	40.7						
[illegible]	6,200	16,200	5,000	20.5	45.1	10.8						
[illegible]	21,000	58,600	9,000	73.6	162	52.6						
[illegible]	61,600	117,000	56,000	215	505	129						
[illegible]	162,000	263,000	100,000	511	882	561						
[illegible]	5,380	8,700	1,580	21.0	52.1	6.55						
[illegible]	8,840	18,800	4,130	56.8	117	25.6						
[illegible]	26,000	51,200	16,500	161	117	112						

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*[illegible] is Boyer ls, [illegible] is Hochheim l, [illegible] is Ozaukee sil, and [illegible] is Ashkum sicl; A is 0 to 2%, B is 2 to 6%, C is 6 to 12% and D is 12 to 20% slope.

**Not applicable.

†SC is the cropping factor used in USLE.

average meteorological conditions on which the MEUL method is based.

The following correction factors based on Fig. II-10 should be applied to sediment loadings from pervious areas.

Season	Erosion Correction Factor
Spring 1975	0.44
Summer 1975	4.00
Fall 1975	1.25
Spring 1976	0.31
Summer 1976	2.3
Fall 1976	5.0
Spring 1977	1.0
Summer 1977	0.66

The loading values must be further adjusted by the delivery ratio (DR) relating loadings at the watershed outlet to those potentially liberated from the source area. The DR is still an unknown quantity which includes such factors as sedimentation and resettling during overland and channel flow, flocculation and agglomeration of suspended particles and removal of pollutants by infiltration during overland flow. An inaccurate method of DR estimation relates DR to the areal size of the watershed as shown in Fig. II-14. Although the method is inaccurate it is as good as any other available. Another factor which must be included is type of drainage. Natural drainage systems with low or no curbs will yield low delivery ratios approximately proportional to the fraction of impervious (e.g., storm sewer) and pervious drainage ditches. Areas with no curbs may show loadings reduced as much as 50% or more as compared to typical urban landscapes of impervious areas (i.e., streets draining into impervious drainage gutters). The loading figures presented in this report are based on the assumption that most of the street pollutants will accumulate near the curb.

Tables II-17 and II-18 present a comparison of measured and estimated sediment and phosphate-P loadings for some major pilot subwatersheds and for areas in a predominantly single land use in the Menomonee River Watershed. In almost all cases the estimated values were higher than the measured ones, a fact partially attributable to assigning a DR-value. For most of the simulated land uses the DR (ratio of measured:estimated loadings) is within the ranges indicated in Fig. II-14. The measured loadings for the fall seasons were low and do not conform to estimated values. It should be noted that Fall 1975 and 1976 seasons were very dry with minimal runoff.

It can also be expected that DR for highly impervious areas will be higher than for largely pervious areas of the same size and DR will be higher in sewered than in unsewered areas with natural drainage ditches.

Simulated unit loadings agree fairly well with measured values under similar meteorological conditions and land use characteristics. An exception has been noted for livestock feedlots where it was impossible to arrive at reasonable values of the soil erodibility factor, K, due to unusually high organic content of feedlot soils and unknown degree of compactness. Available measured loading values from feedlots (28,29) deviate significantly from simulated ranges; however, more research is necessary to obtain more realistic data.

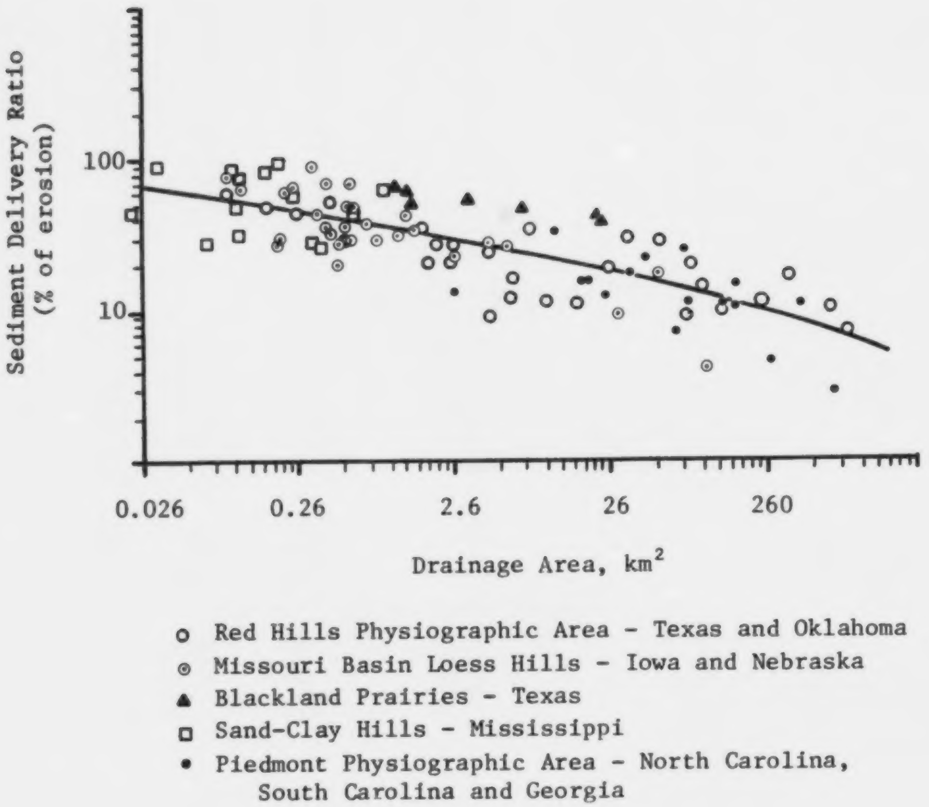

Fig. II-14. Sediment delivery ratio versus drainage area (% of eroded soil material transported to the downstream outlet of streams based upon their drainage area) (27).

Table II-17. Comparison of simulated and measured sediment and phosphate loadings in subwatersheds with mixed land uses (measured loadings are taken from (26))

Land Use	Area, %	Impervious areas, %	Sediment, kg/ha			PO$_4$-P, kg/ha		
			Spring	Summer	Fall	Spring	Summer	Fall
Donges Bay Rd. (463001), 2144 ha								
Commercial	2.6		200	400	200	0.30	0.70	0.25
High density residential	0.05		400	800	60	0.60	0.80	0.70
Medium density residential	3.9		200	400	150	0.50	0.80	0.40
Low density residential	4.7		120	250	50	0.35	0.50	0.10
Row crops	74							
Contributing	32		1,655	100	10	3.0	0.18	0.00
Pasture A	5		134	206	60	0.23	0.37	0.11
Pasture B	5		487	690	135	0.87	1.22	0.24
Wetlands	2.3		119	248	18	0.21	0.45	0.03
Feedlots	0.5		2,100	4,525	750*	5.90	12.89	2.0
Developing	1.6		2,800	4,150	1,200*	5.67	7.45	2.5
Estimated mean			597	212	50	1.18	0.40	0.09
Measured, arithmetic mean			304	39		0.61	0.07	
weighted mean			107	62		0.20	0.06	
Delivery ratio, weighted			0.18	0.29		0.17	0.15	
Noyes Creek** (413011), 552 ha								
Industrial	1.8	60	880(80)***	1,020(220)	460(60)	0.70	1.1	0.30
Commercial	35	60	700(100)	650(150)	250(50)	0.50	0.60	0.16
High density residential	3.8	70	730(130)	820(170)	350(50)	0.60	0.80	0.16
Medium density residential	15.8	40	360(160)	470(270)	140(60)	0.45	0.60	0.15
Low density residential	14.6	10	180(160)	290(270)	70(60)	0.30	0.45	0.12
Park and recreation A	23	2	55	64	30	0.09	0.13	0.09
Woodlands A	-	-	-	-	-	-	-	-
Developing A	2.7	2	3,000	6,600	1,260*	4.1	6.2	3.6
Landfill A	2.7	2	3,000	6,600	1,260*	4.1	6.2	3.6
Water	0.3							
Estimated mean		35	547	762	155	0.56	0.78	0.32
Measured, arithmetic mean			840	389	136++	0.61	0.36	0.01
weighted mean			566	566	153			
Delivery ratio, weighted			1.0	0.74	0.99			
Honey Creek (413006), 2,803 ha								
Industrial	0.9		855(55)	864(64)	460(60)			
Commercial	27.9		655(55)	564(64)	250(50)			
High density residential	3.3		655(55)	714(64)	350(50)			
Medium density residential	24.2		255(55)	264(64)	115(35)			
Low density residential	15.6		75(55)	84(64)	45(45)			
Developing A	1.8		3,500	7,000	1,200			
Row crops	0.07		-	-	-			
Parks and recreation A	18.6		55	64	30			
Woodlands	0.6		-	-	-			
Wetland	0.3		-	-	-			
Landfill	0.5		2,500	5,500	1,050**			
Estimated mean			368	425	258			
Measured, arithmetic mean			417	225	28			
weighted mean			294	287	41			
Delivery ratio, weighted			0.80	0.68	0.16			
Schoonmaker Creek+++ (413010), 179 ha								
Commercial	26.6	90	350(50)	500(50)	190(10)			
High density residential	0.5	90	350(50)	800(50)	210(30)			
Medium density residential	39.1	60	200(50)	600(200)	160(60)			
Low density residential	27.2	25	200(170)	280(200)	75(60)			
Developing A	3.0	1.6	1,500	2,300	660*			
Parks and recreation	9.0	5.0	27	32	15*			
Estimated mean		54	277	531	120			
Measured, arithmetic mean			157	147	33			
weighted mean			120	210	45			
Delivery ratio			0.43	0.40	0.38			

*Corrected for the area used.
**No cleaning in spring, medium maintenance in summer and fall.
***( ) amount contributed by pervious areas.
+Assume that 50% originated fromm pervious areas.
++Data for Fall 1976 excluded due to unusually dry weather.
+++Assume good cleaning.

Table II-18. Comparison of simulated and measured sediment and phosphate loadings in predominantly single land use areas (measured loadings are taken from (26))

Type of loading	Sediment, kg/ha			PO_4-P, kg/ha		
	Spring	Summer	Fall	Spring	Summer	Fall
Timmerman Airport (413614): 140 ha, 1% mean slope, 18% impervious, commerical						
Estimated mean	36	55	15	0.06	0.10	0.05
Measured, arithmetic mean	16	68	4.2	0.03	0.09	0.03
weighted mean	16	55	6			
Delivery ratio	0.44	1.0	0.40			
Brookfield Square (6830089): 61 ha, 2% mean slope, 50.4% impervious, commercial						
Estimated mean	200	310	120	0.3	0.3	0.1
Measured, arithmetic mean	350	136	5	0.26	0.16	0.02
weighted mean	350	180				
Stadium Interchange (413615): 64 ha, 2% mean slope, 44.6% impervious, transportation						
Estimated mean	250	450	100	0.42	0.60	0.15
Measured, arithmetic mean	230	353	28	0.24	0.32	0.04
Allis Chalmers (413616); 49 ha, 89.9% impervious, industrial						
Estimated mean	1,200	1,600	1,600	0.9	1.3	0.5
Measured, arithmetic mean	79	913	-	0.45	2.38	0.08

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APPENDIX II-A

DETAILED STATISTICAL EVALUATION OF STREET LITTER ACCUMULATION

It has been realized that a simple unit loading value may not be representative of the surface pollution accumulation process. Instead, a mass balance model can be developed which may better represent the dynamic character of the street refuse accumulation. The model is based on the following simple mass balance equation (see Fig. II-7 for more detail):

$$\frac{dl}{dt} = L_D - L_R \qquad \text{Eq. (A-1)}$$

L is the polllutant accumulation on the surface, g/curb m/day

L_D is the pollutant deposition rate, g/curb m/day

L_R is the pollutant removal rate from the surface, g/curb m/day

The simple mass balance equation presented above can be expanded by identifying the significant factors which affect deposition and removal from street surfaces. The primary sources can be related to fallout of atmospheric pollutants, motor vehicle usage and deposition of street litter.

Traffic can contribute significantly to pollutant deposition in urban areas. Large amounts of toxic metals in storm water runoff are often attributed to motor vehicle emissions and to the breakdown of road surface materials and vehicle parts.

The variables affecting the pollutant deposition rate on impervious urban areas can be combined to yield the following equation:

$$L_D = (ATFL)\ (SW/2) + A_1\ A\ (SW/2)\ (POA) + A_2(RD) + A_3(TD)\ (RCC)$$

Eq. (A-2)

where

ATFL is a coefficient reflecting deposition from stationary combustion processes and atmospheric fallout, g/ha/day
SW is the street width, m
A_1 is a coefficient reflecting the effect of open areas on pollutant deposition
POA is % open area in the vicinity of the site
A_2 is a coefficient reflecting the effect of residential density on pollutant accumulation
RD is the residential density, dwelling units/ha

A_3 is a coefficient reflecting the effect of traffic on pollutant accumulation
TD is traffic density, thousand axles/day
RCC is road composition and conditions which is a value based on scale determined from regression analysis

At the same time that pollutants are being deposited on the surface they are being removed. Factors which should be investigated as affecting the removal rate include wind speed, traffic speed, and curb and average height of buildings. The equation for street surface refuse removal can be formulated as:

$$L_R = A_4 [f_1(H)\ f_2(WS,TS)]L \qquad \text{Eq. (A-3)}$$

where

A_4 is a coefficient reflecting the rate of pollutant removal due to the combined effect of wind and traffic speed
H is curb height, cm
WS is average wind speed, km/hr
TS is average traffic speed, km/hr

The function $f_1(H)$, describes the effect of curb height on pollutant removal and can be modeled as:

$$f_1(H) = e^{-\beta H} \qquad \text{Eq. (A-4)}$$

where β is a statistical coefficient.

The above model was applied to a set of field data. Since the Menomonee River Watershed data do not yet provide a representative data sample, the data sample was supplemented by field measurements of street refuse accumulation in the Washington, D.C. area (A-1).

The solution to Eq. 12 will yield the following formula:

$$L = \frac{A}{B}(1 - e^{-Bt}) + C \qquad \text{Eq. (A-5)}$$

where

t is time from last street cleaning or rain
A and B are variables determined for each constituent
C is a constant

The Washington, D.C. data (A-1), contain about 73 measurements on 7 different sites. Although the number of sites is probably too low to provide a sufficient spread of independent variables the statistical analysis did provide some answers as to the significance of the variables involved.

The best fit equations for four typical constituents, i.e., which were statistically significant are as follows:

Dust and dirt suspended solids -

$$DDSS = \frac{A}{B}(1 - e^{-Bt}) + C \qquad \text{Eq. (A-6)}$$

$$A = ATFL(\frac{SW}{2}) - 5.02(RD) - 6.29(POA) + 1.15(TD)$$

$$B = 0.0116e^{-0.088H} (TS + WS)$$

$$C = 0.0$$

Multiple correlation coefficient $R = 0.86$

Similarly:

Dust and dirt chemical oxygen demand -

$$DDCOD = \frac{A}{B}(1-e^{-Bt}) + C \qquad \text{Eq. (A-7)}$$

$$A = 2.60(\frac{SW}{2}) - 0.28(RD - 0.51(POA) + 0.52(TD)$$

$$B = 0.142e^{-0.98H} (TS + WS)$$

$$C = 0$$

Multiple correlation coefficient $R = 0.71$

Dust and dirt volatile suspended solids -

$$DDVSS = \frac{A_1}{B_1}(1 - e^{-B_1 t}) - \frac{A_2}{B_2}(1 - e^{-B_2 t}) + \frac{A_3}{B_3}(1 - e^{-B_3 t}) + C \qquad \text{Eq. (A-8)}$$

$$A_1 = 1.46(\frac{SW}{2})$$

$$B_1 = 0.024 e^{-0.05H} (TS + WS)$$

$$A_2 = 0.25(RD) + 0.31(POA)$$

$$B_2 = 0.048 e^{-0.05H} (TS + WS)$$

$$A_3 = 0.069(TD)$$

$$B_3 = 0.105\ e^{-0.05H}\ (TS + WS)$$

$$C = 0$$

Multiple correlation coefficient $R = 0.65$

Dust and dirt lead -

$$DD\ Lead = \frac{A_1}{B_1}(1 - e^{-B_1 t}) - \frac{A_2}{B_2}(1 - e^{-B_2 t}) + \frac{A_3}{B_3}(1 - e^{-B_3 t}) + C$$

$$A_1 = 0.131\ \frac{SW}{1}$$

$$B_1 = 0.036\ e^{-0.03H}\ (TS + WS)$$

$$A_2 = 0.027(RD)$$

$$B_2 = 0.026\ e^{-0.03H}\ (TS + WS)$$

$$A_3 = 0.013\ (TD)$$

$$B_3 = 0.053\ e^{-0.03H}\ (TS + WS)$$

$$C = -0.825$$

Multiple correlation coefficient $R = 0.80$

Table II-A-1 lists the partial correlation coefficients for the above variables. From the table it can be seen that in all four cases the overall functional relationship is at a significant level. The dependent variables which have the most significant effect on the independent variables vary with the character of the variables. As might be expected, traffic density may have a very significant effect on the magnitude of the accumulation of dust and dirt constituents, particularly lead. On initial inspection it may seem surprising that the regression coefficients have a negative value for POA and RD. One would expect that quantity of street refuse would increase with increasing housing density or open area (i.e., area without significant vegetation). On the other hand, just the opposite can be true if one realizes that a significant portion of street refuse originates from vegetation--lawns, trees and shrubs--which are inversely proportional to housing density (RD) or open area (POA). Thus, it seems that trees and vegetation near impervious areas may contribute significantly (especially during the fall season) to pollutant loading.

The above equations represent the best combination of variables which

Table II-A-1. Partial and multiple correlation coefficients between dust and dirt pollutants and factors affecting their accumulation

Independent variable	Partial r of dependent variable*				Multiple R
	SW	RD	POA	TD	
Suspended solids	0.28	-0.30	-0.34	0.34	0.86
COD	0.26	-0.16	-0.27	0.15	0.71
Volatile suspended solids	0.13	-0.23	-0.20	0.26	0.65
Lead	0.067	-0.113	0.0018	0.40	0.80

*SW is street width, RD is residential density, POA is percent of open area, TD is traffic density, H is curb height, TS is traffic speed and WS is wind speed.

were investigated. Other combinations which yielded lower statistical correlations included the effect of traffic speed on pollutant accumulation (as in the form of TD x TS or TD x TS^2), excluding some insignificant variables and others.

Equations (A-6) to (A-9) indicate that as the quantity of deposited pollutants increases with prolonged dry periods, more particles can be removed by wind and traffic and the actual differential deposition rate decreases. This fact was also observed by Sartor et al. (A-2) and is documented in Fig. II-A-1.

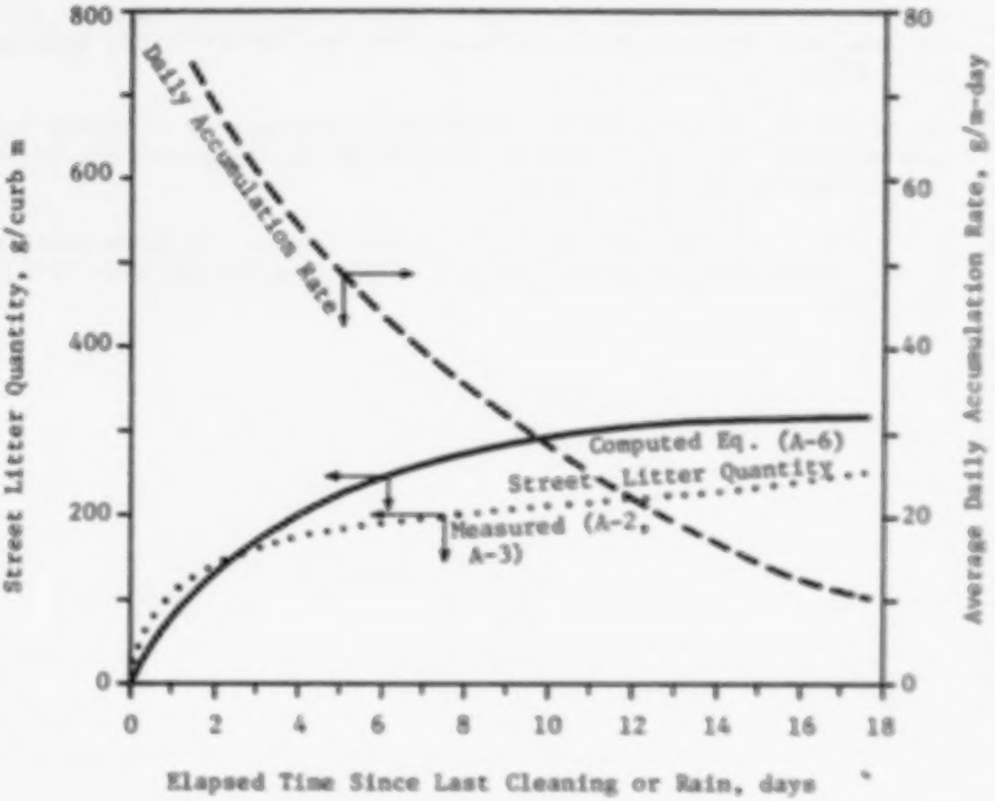

Fig. II-A-1. Effect of dry periods on the quantity of street litters.

REFERENCES-APPENDIX II-A

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APPENDIX II-B

SIMULATED LOADING DIAGRAMS

Loadings for impervious urban land uses (Figs. II-B-1 to II-B-6) reflect values from areas under slope category B (2 to 6%). Average loadings can be read directly from the loading diagrams. Loading diagrams for volatile suspended solids and Pb are available but are not presented in this report.

Loadings from pervious areas shown in Figs. II-B-7 to II-B-16 reflect values from a 1 km^2 area under soil slope category C (6 to 12%). To obtain average loadings, loading diagram related to the R-factor must be transformed to a probability distribution loading plot using the cumulative frequency chart in Fig. II-10. The cropping factor, SC, on all loading diagrams is 0.01. To obtain loadings for each land use with SC other than 0.01 multiply the values from the graph by 100 and SC factors in Table II-16. To transform loadings to other slopes and areal units, values should be multiplied by slope or area correction factors presented in Figs. II-11 to II-13. Loading diagrams for phosphate-P are available but are not given in this report.

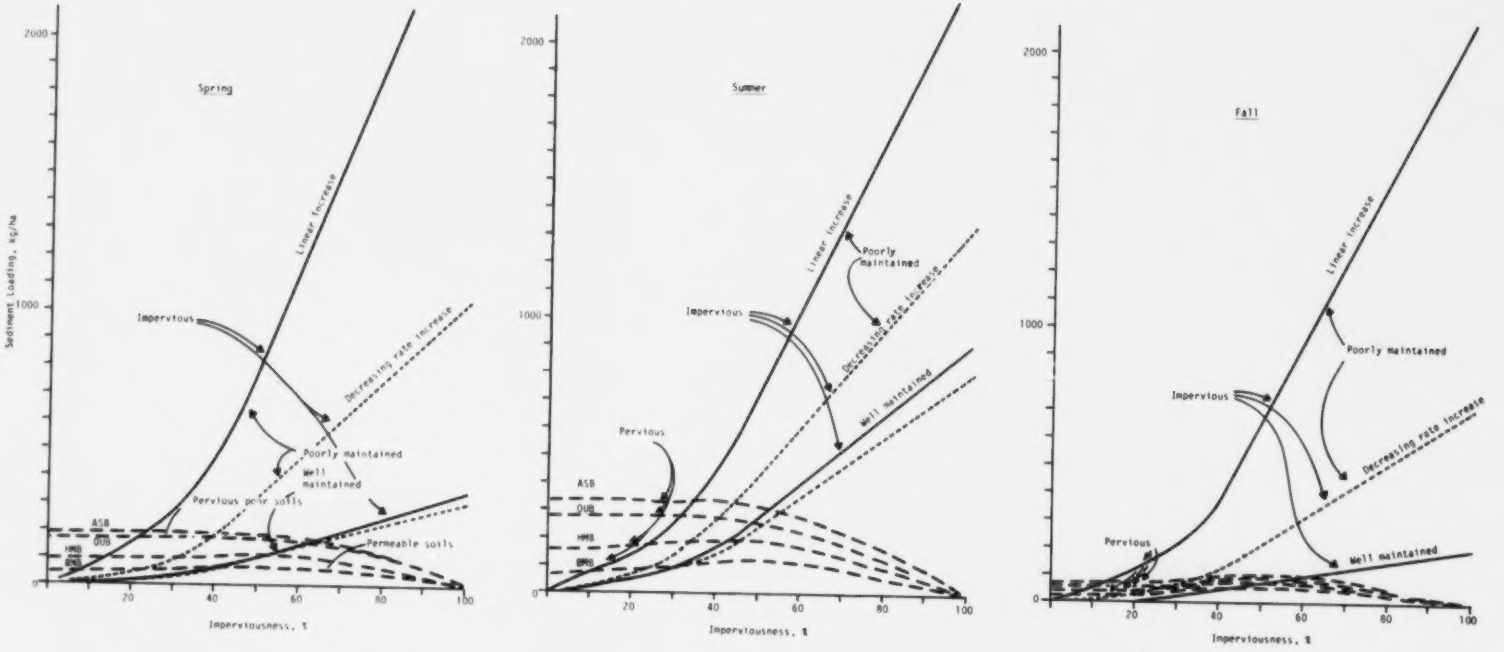

Fig. II-B-1. Sediment loadings from residential areas.

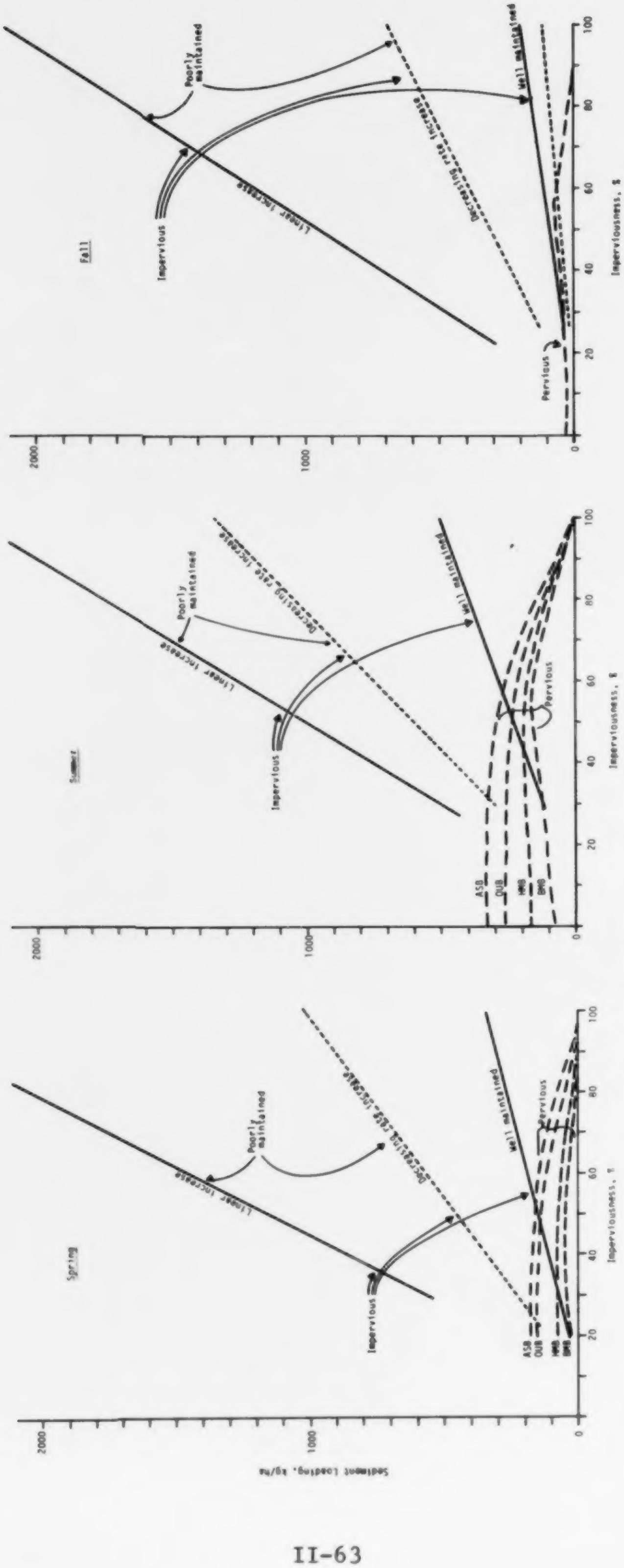

Fig. II-B-2. Sediment loadings from commercial areas.

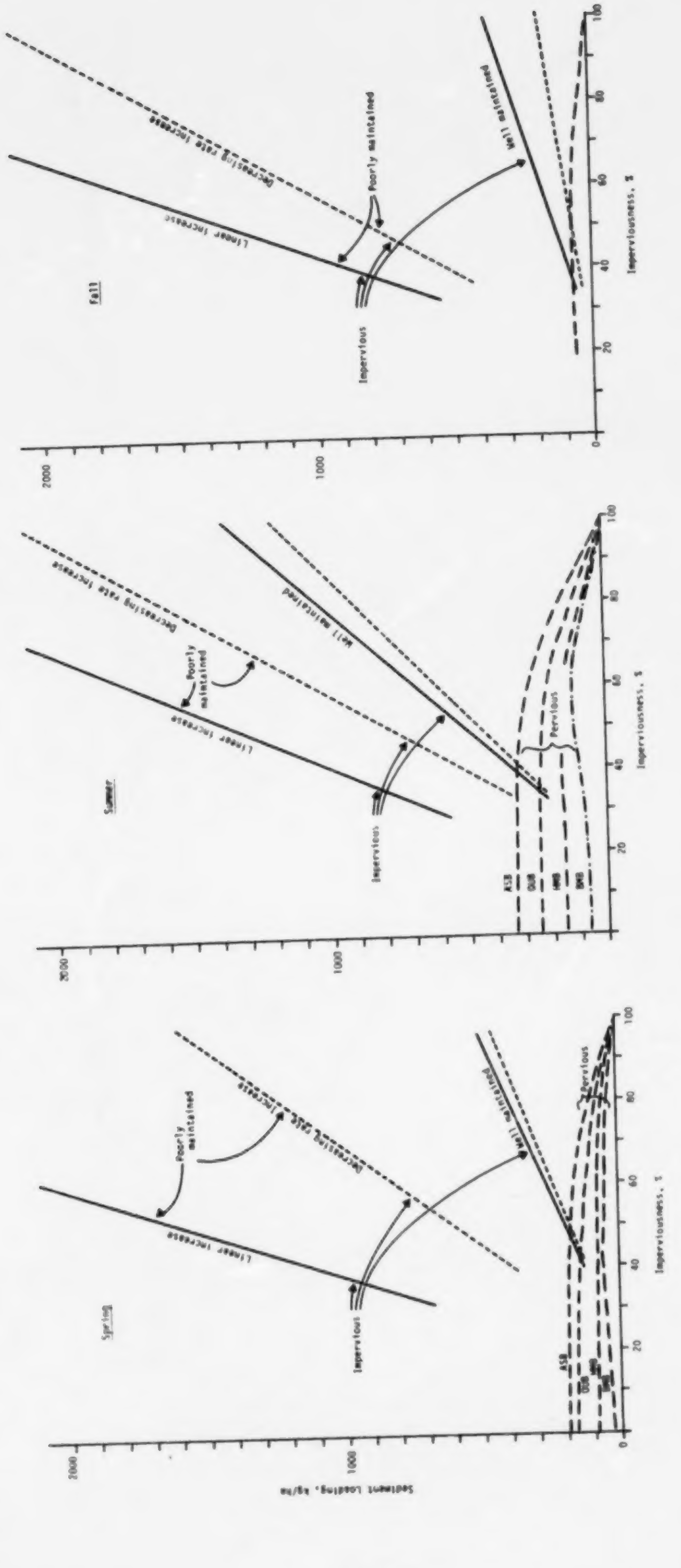

Fig. II-B-3. Sediment loadings from industrial areas.

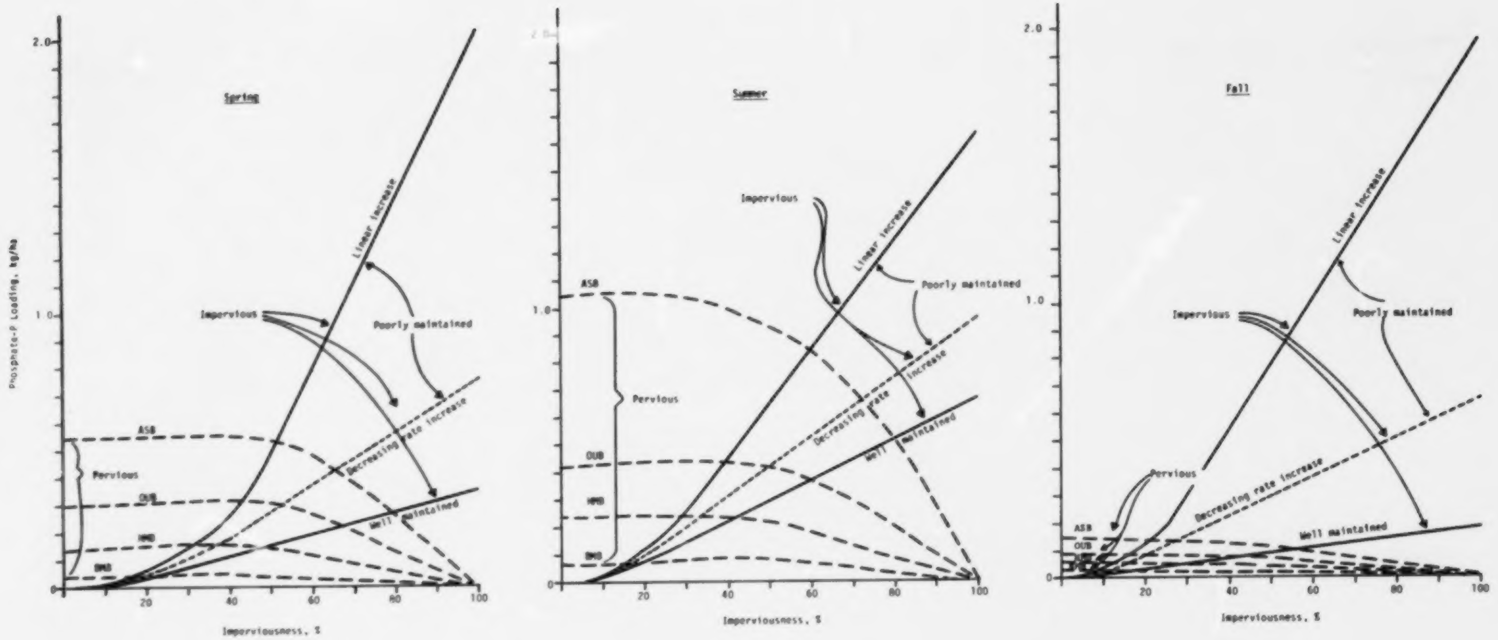

Fig. II-B-4. Phosphate-P loadings from residential areas.

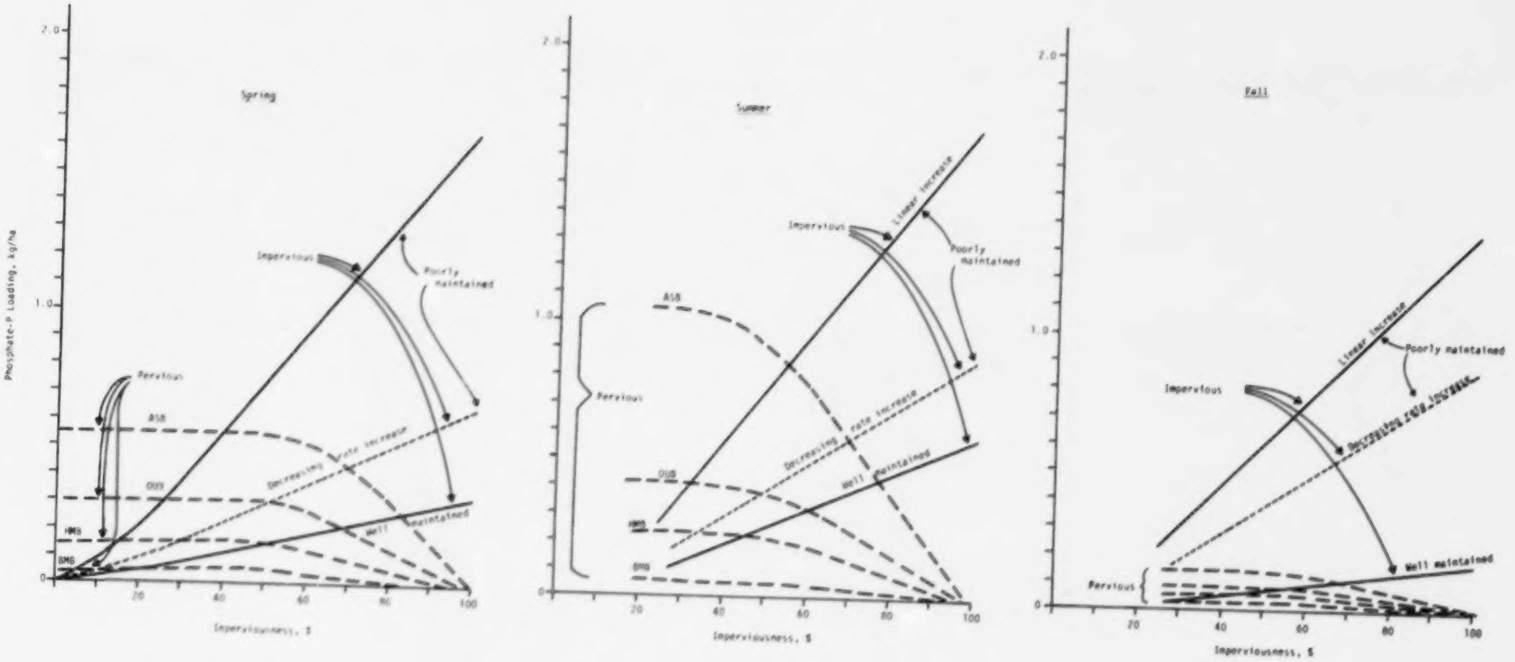

Fig. II-B-5. Phosphate-P loadings from commercial areas.

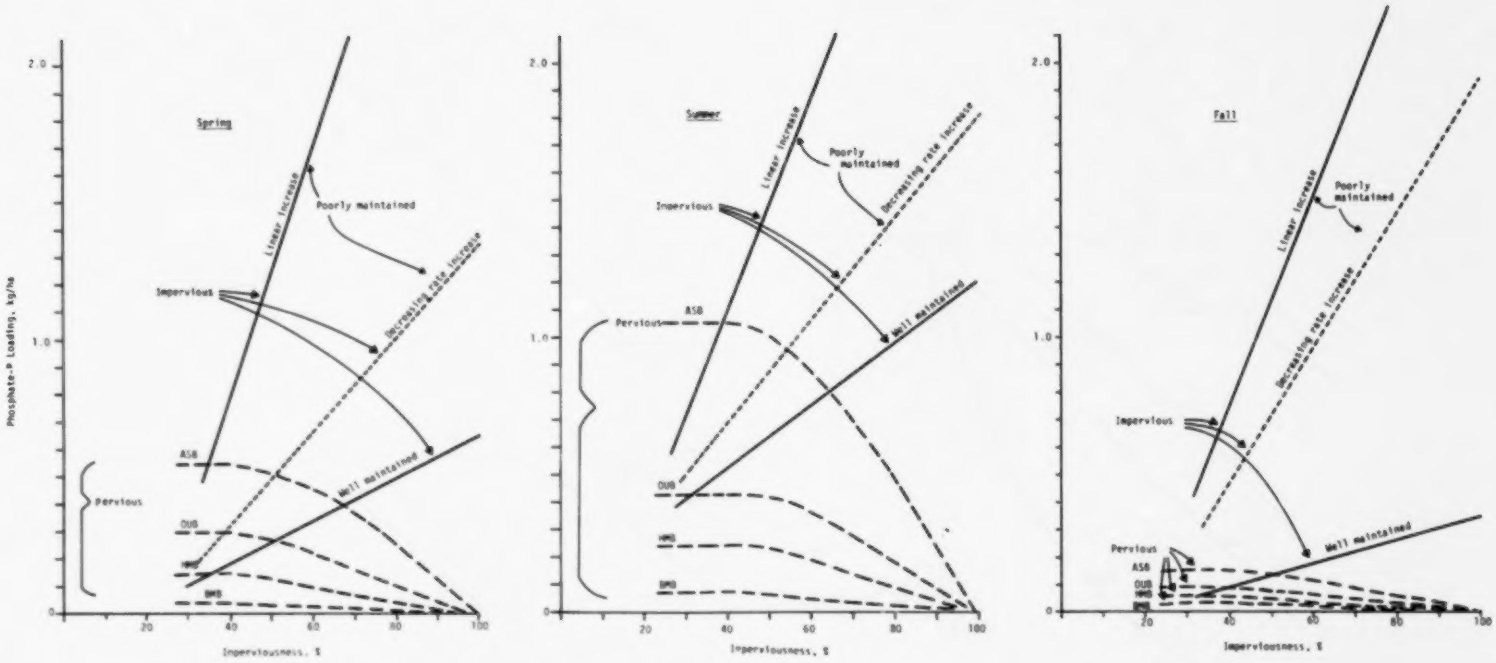

Fig. II-B-6. Phosphate-P loadings from industrial areas.

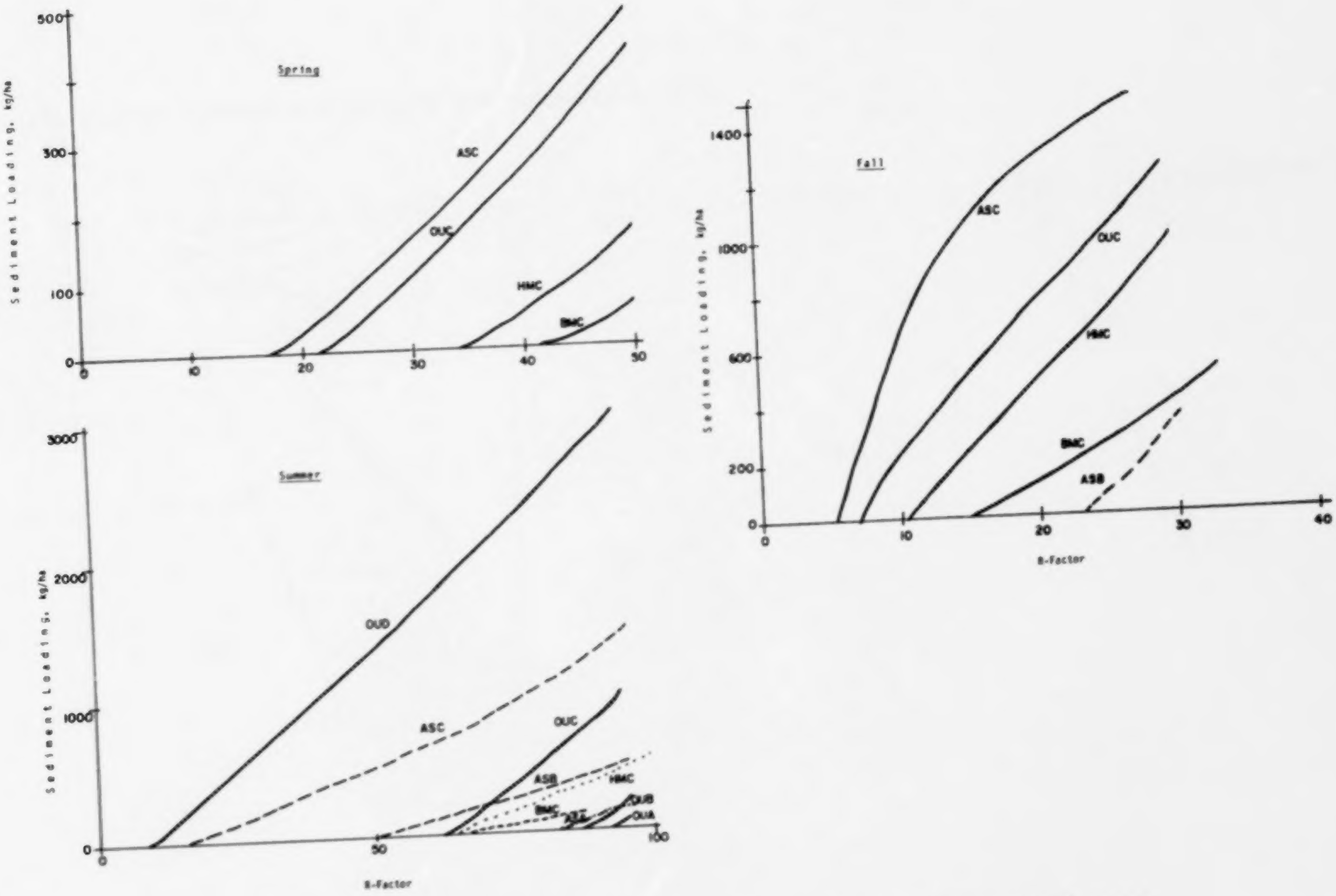

Fig. II-B-7. Relationship of sediment loadings and R-factor in row crop-woodland areas.

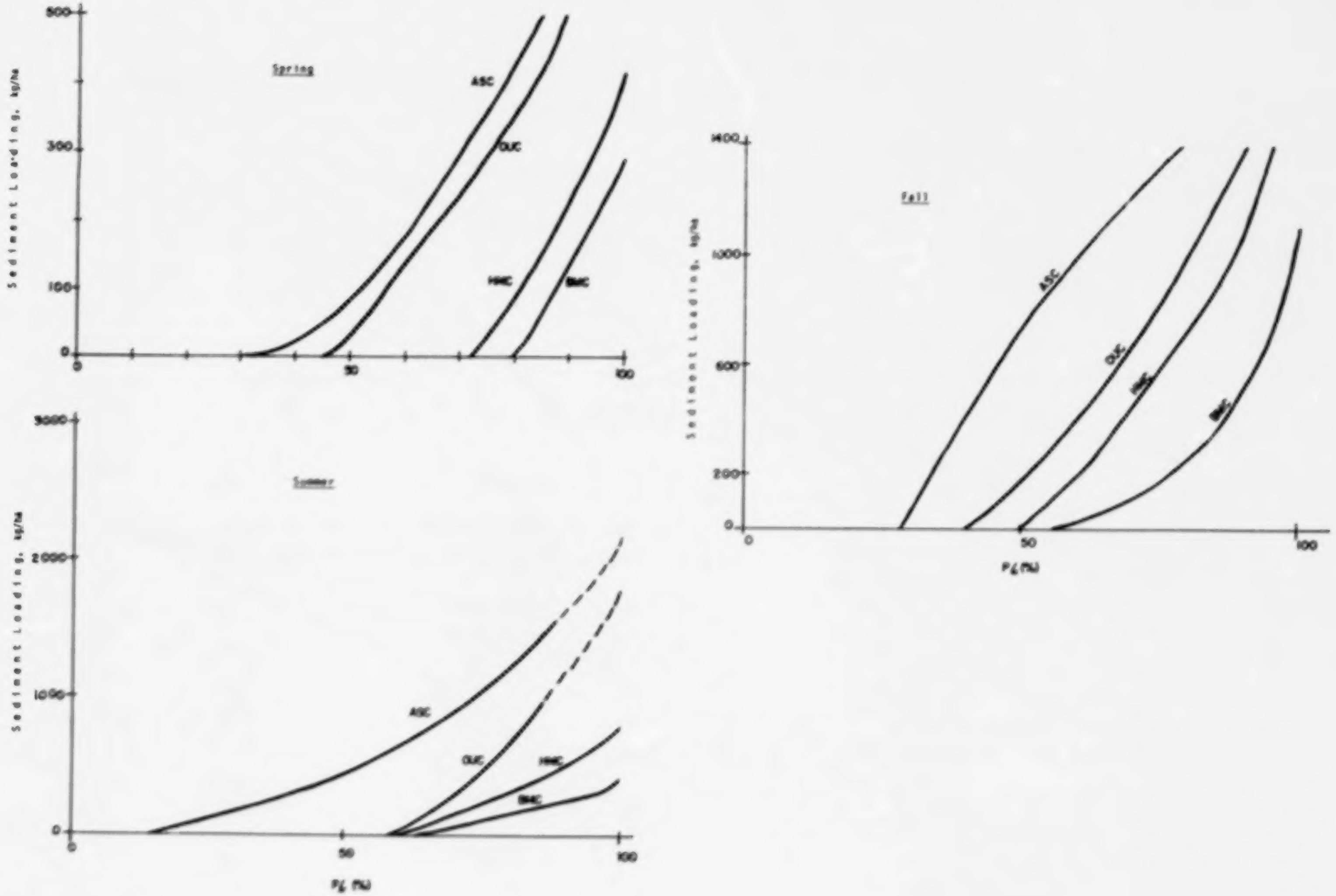

Fig. II-B-8. Probability distribution of sediment loadings in row crop-woodland areas.

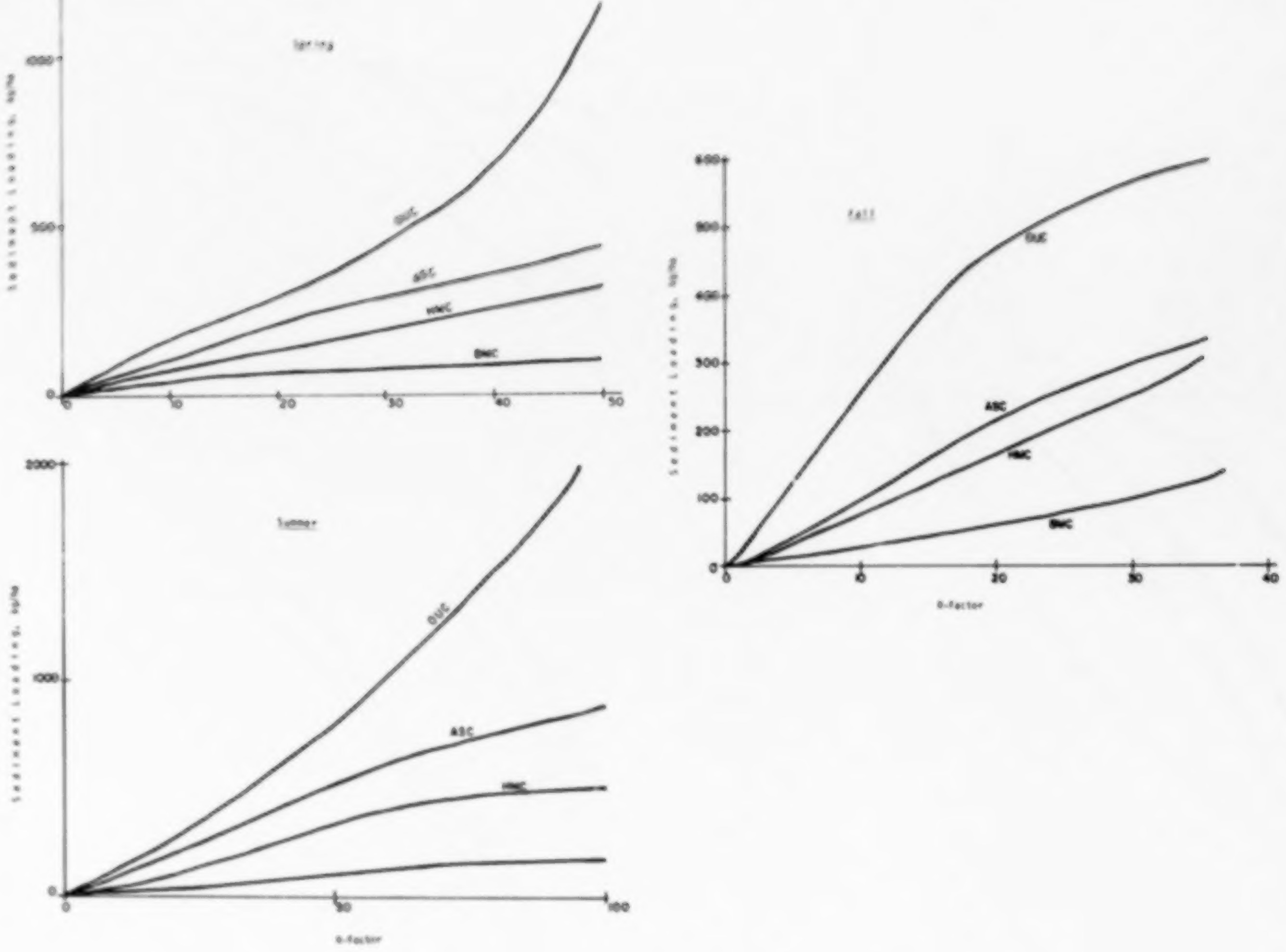

Fig. II-B-9. Relationship of sediment loadings and R-factor in feedlots.

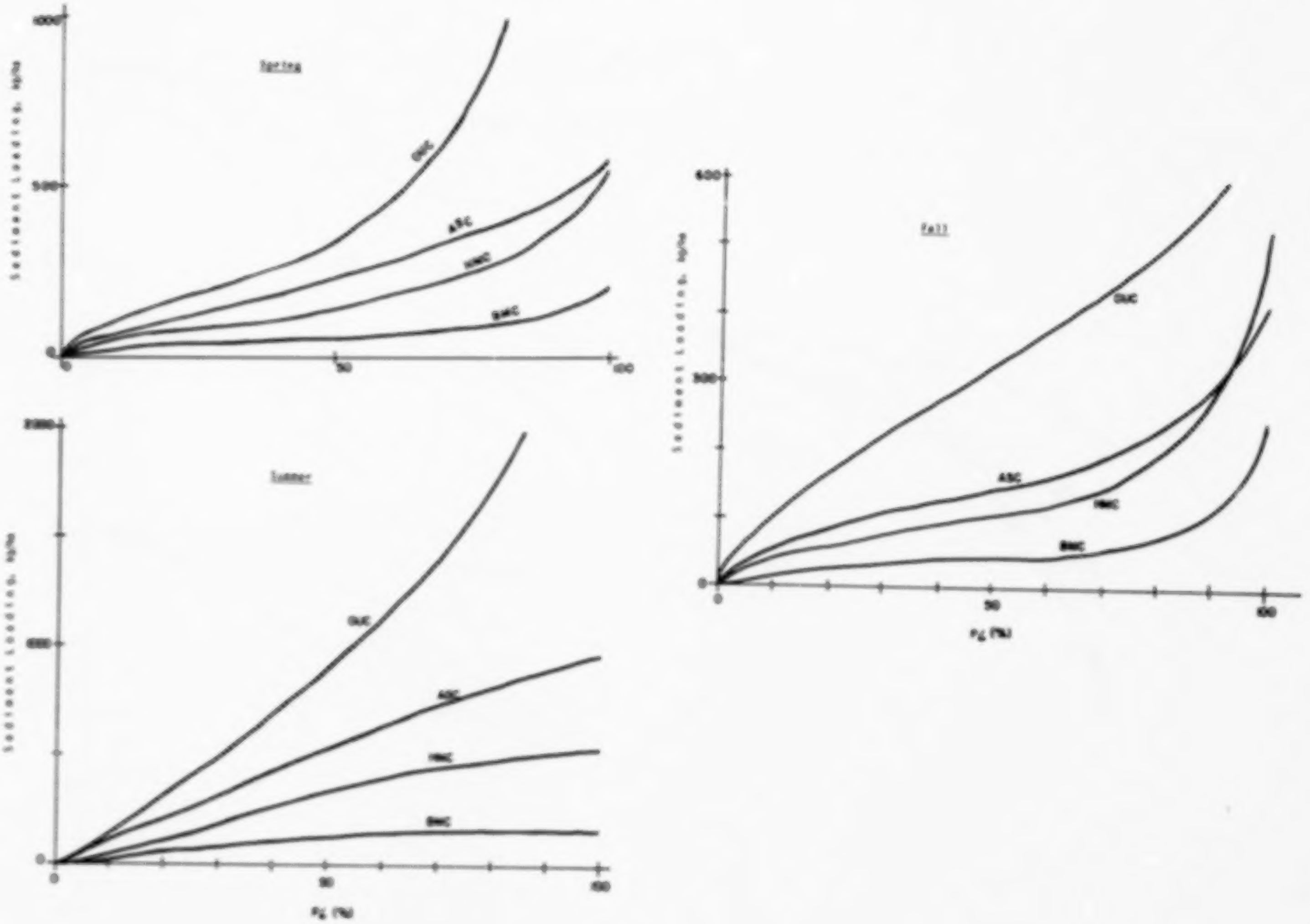

Fig. II-B-10. Probability distribution of sediment loadings in feedlots.

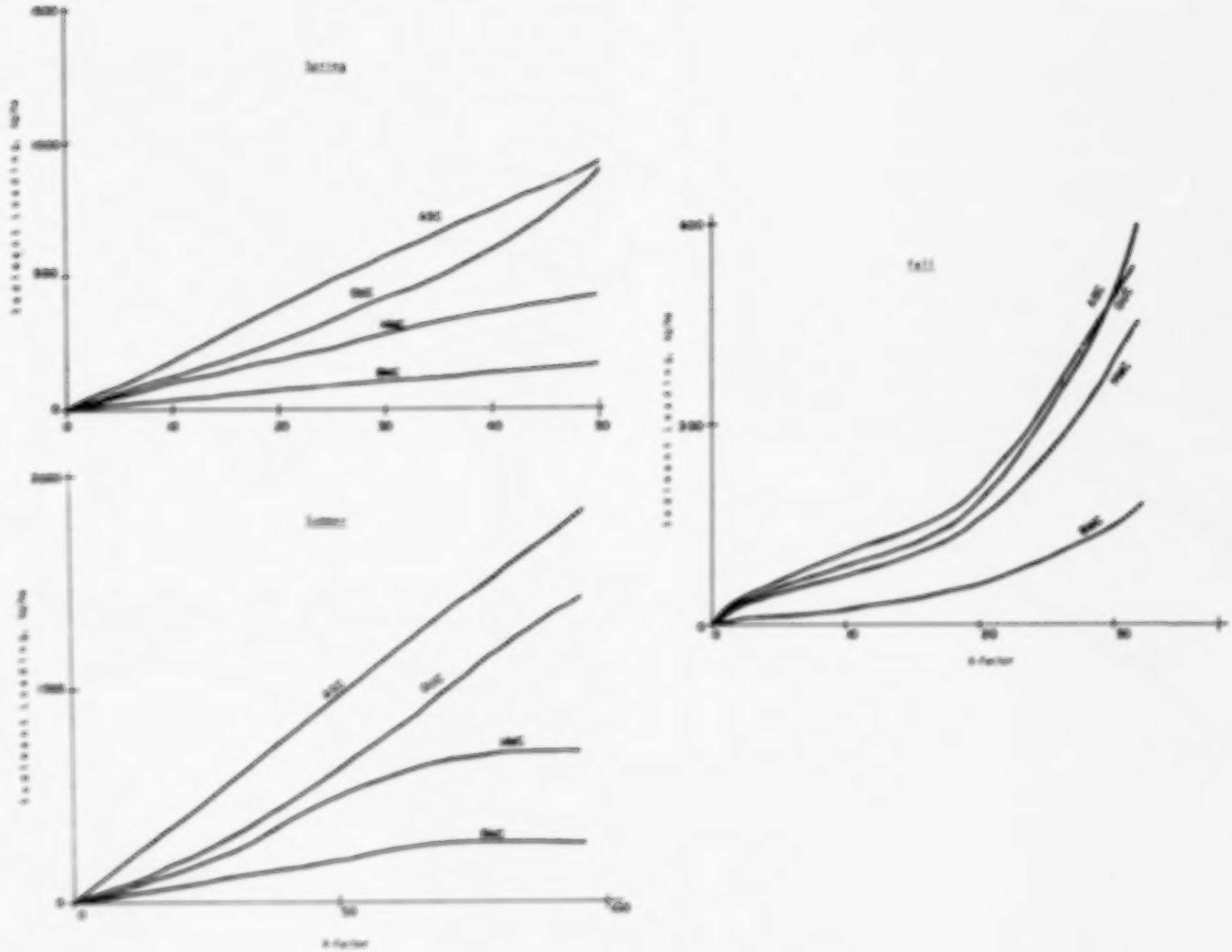

Fig. II-B-11. Relationship of sediment loadings and R-factor in pastures.

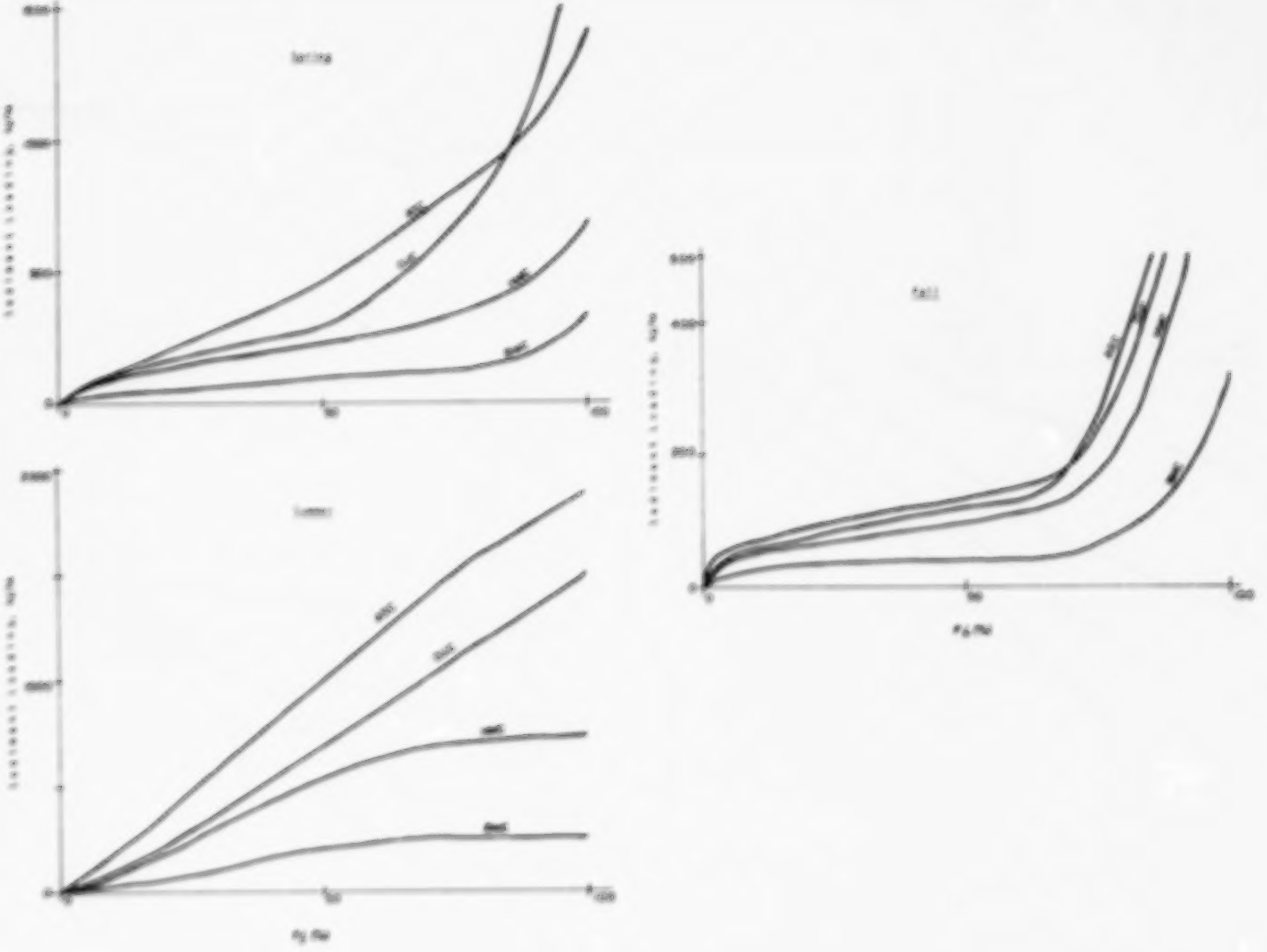

Fig. II-B-12. Probability distribution of sediment loadings in pastures.

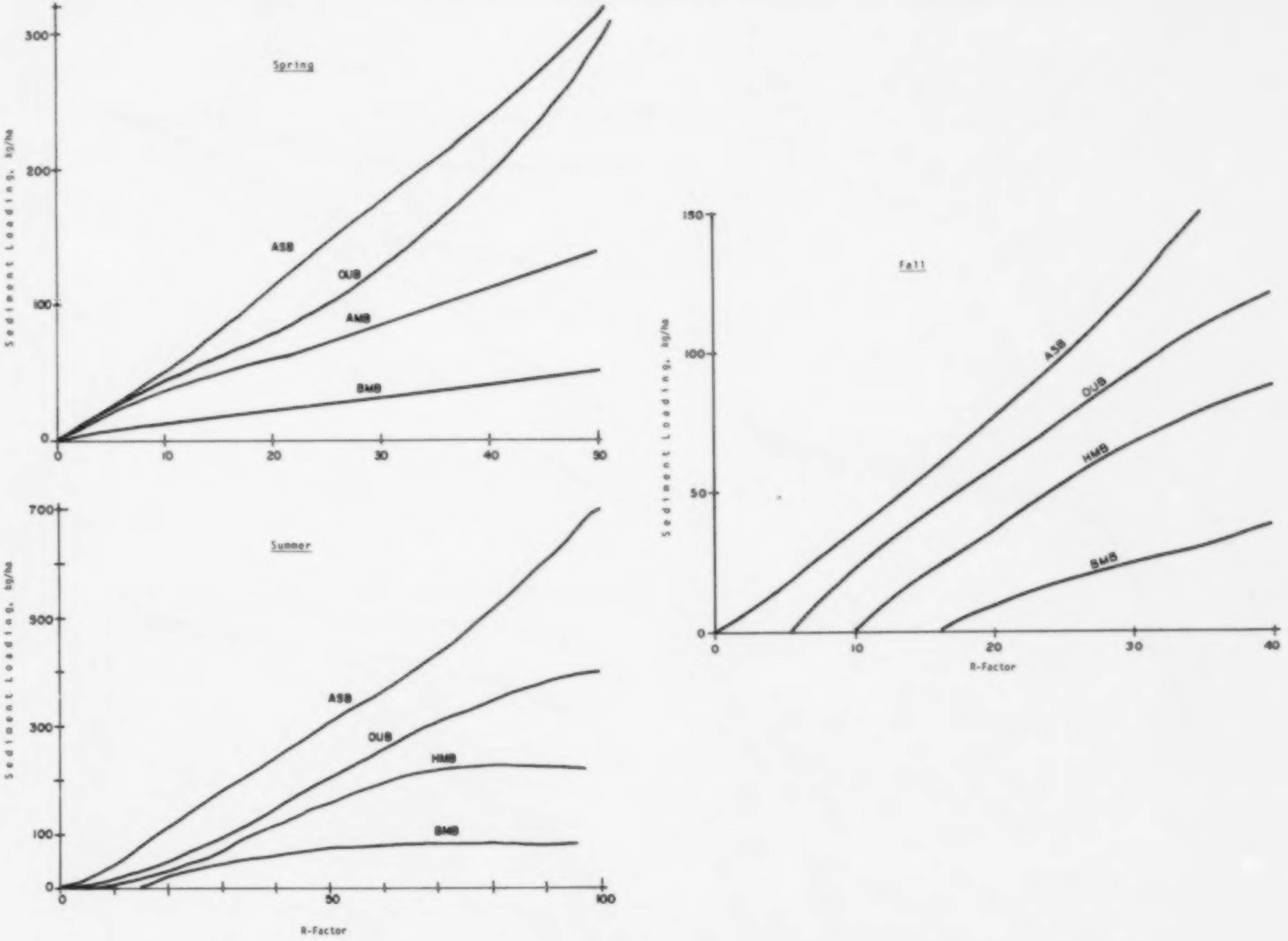

Fig. II-B-13. Relationship of sediment loadings and R-factor in wetlands.

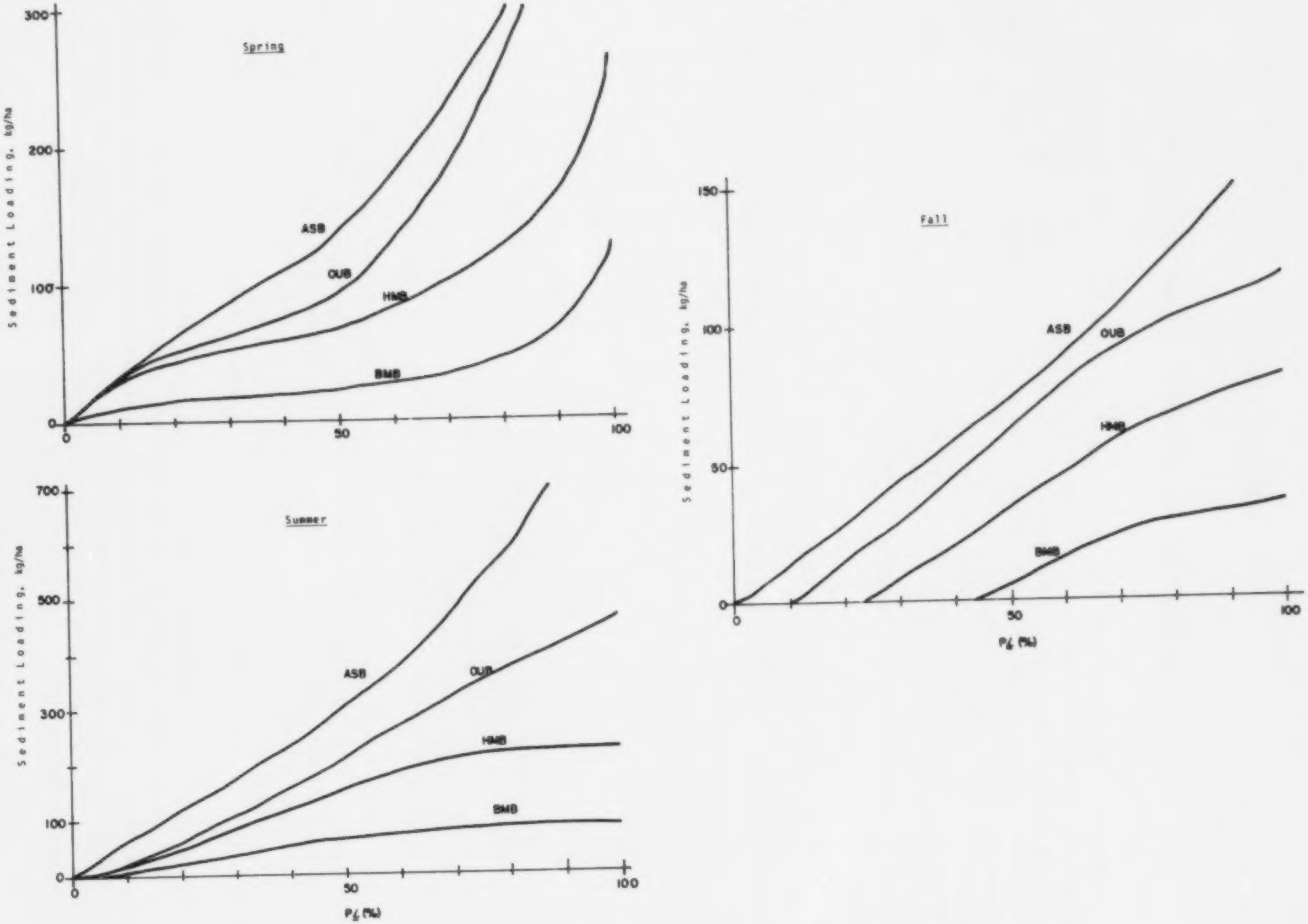

Fig. II-B-14. Probability distribution of sediment loadings in wetlands.

APPENDIX II-C

REMEDIAL MEASURES AND NON-POINT POLLUTION CONTROL

Remedial measures can be categorized using a macro or micro scale. The former may result in better land use practices and zoning, legislation limiting marketing certain potentially-hazardous pollutants or better farming practices. These measures are usually long-term remedies and take longer periods of time to implement. Micro-scale remedial measures include better management and control of existing land uses. In urban settings, limiting the non-point pollution can take place either at the source (maintenance and cleaning) or at the area outlet (storage and treatment). In non-urban settings, the control is limited to better farming practices and erosion control.

A literature review by the Wisconsin Department of Natural Resources (C-1) compiled and presented possible management practices to control water quality of urban runoff. The control techniques mentioned included:

Source control

- Increased infiltration
- Retention of runoff
- Reduction of erosion
- Reduction of contaminant deposition
- Street sweeping

Outfall treatment and collection control

- Reduction in channel erosion
- Infiltration and sedimentation basins
- Storage basins to equalize flow
- Physical, chemical and biological treatment

The study concluded that in low density urbanizing areas the quality of stormwater runoff is most efficiently handled by systems incorporated into the development stage such as zoning, control of developing areas, increased perviousness and optimal design of stormwater conveyance systems. In high density, developed areas, runoff is handled by good street cleaning practices and through one of a series of treatment methods subsequent to collection.

Source control of urban-related pollution, which reduces on-site pollutant generation or prevents pollutants from leaving the small drainage areas at which a disturbance occurs, is less expensive and more effective than remedial measures once the pollutants leave the site and move downstream. Control of runoff pollution by collection systems is more expensive than on-site source control but less costly than treatment at the outfall.

Treatment of urban runoff may be feasible only for highly developed areas where source control and collection control are not possible.

The difference between frequently cleaned and poorly maintained (no cleaning) urban areas can be seen in Table II-15. Although Table II-15 represents simulated pollutant loadings the importance of street cleaning is evident. Figures II-C-1 and II-C-2 show the simulated effect of street cleaning frequency and efficiency on sediment loadings. The average efficiency of street sweepers for the suspended particulate materials (dust) is about 50% (C-2) but due to the fact that P is associated mostly with the fine fractions of street dust and dirt the expected efficiency of P removal is only about 22%. The effects of street sweeping are much higher during a dry season and when a linear accumulation of street pollutants is assumed.

Other remedial measures include increasing pervious areas within urban settings and reducing impervious areas directly connected to surface runoff channels. Installing pervious parking areas, introducing seepage beds and basins, and disconnecting roof drains from storm sewers can be listed as possible examples. These measures can be ineffective if the area is located on impermeable soils or on steep slopes since the conveyance of runoff from the pervious area would create more erosion and pollutant washout from these soils. Pervious areas should not be left bare. Permanent or temporal surface protection, such as lawns, temporary seeding, or application of mulch or chemicals should be practiced to control erosion and pollutant washout.

Street curbs and highway barriers represent obstacles at which surface suspended pollutants (dust) can accumulate. Studies by Sartor et al. (C-2) and Sartor and Boyd (C-3) indicated that 90% of surface suspended pollutants are located within 1 m of the curb. One would suspect that the curb height can--to some degree--affect the amount of pollutants accumulated. To provide some insight into the validity of this hypothesis, a sensitivity analysis of Eq. (A-6) was performed (Fig. II-C-3). Thus, lower curb heights may result in less pollutant accumulation near the curb since some of the deposits can be removed by wind and traffic and deposited in adjacent pervious areas where they are less available for transport. Obviously, lowering curb sizes would be effective only if the streets are surrounded by pervious areas.

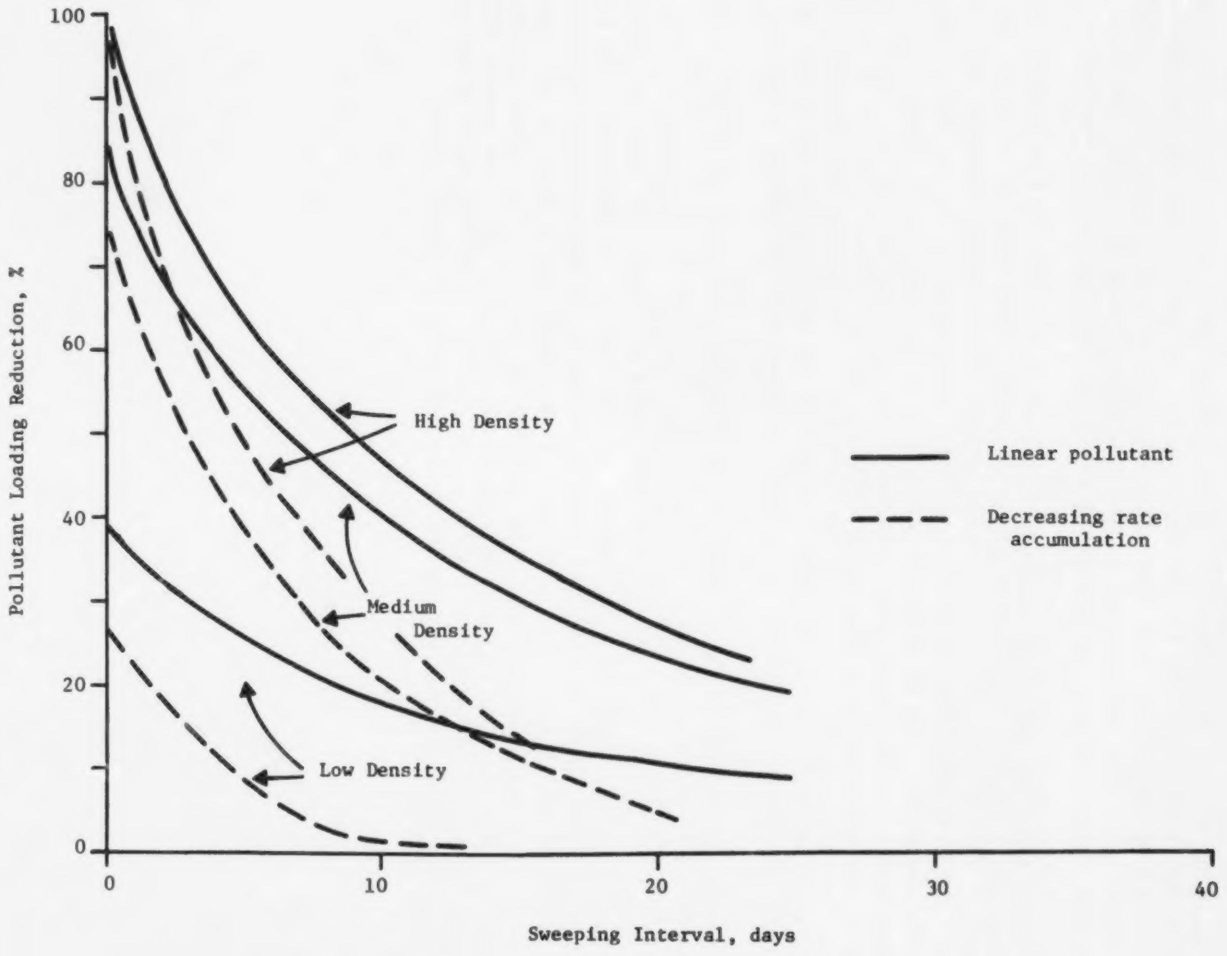

Fig. II-C-1. Effect of sweeping interval on pollutant loadings (sweeping efficiency = 50%).

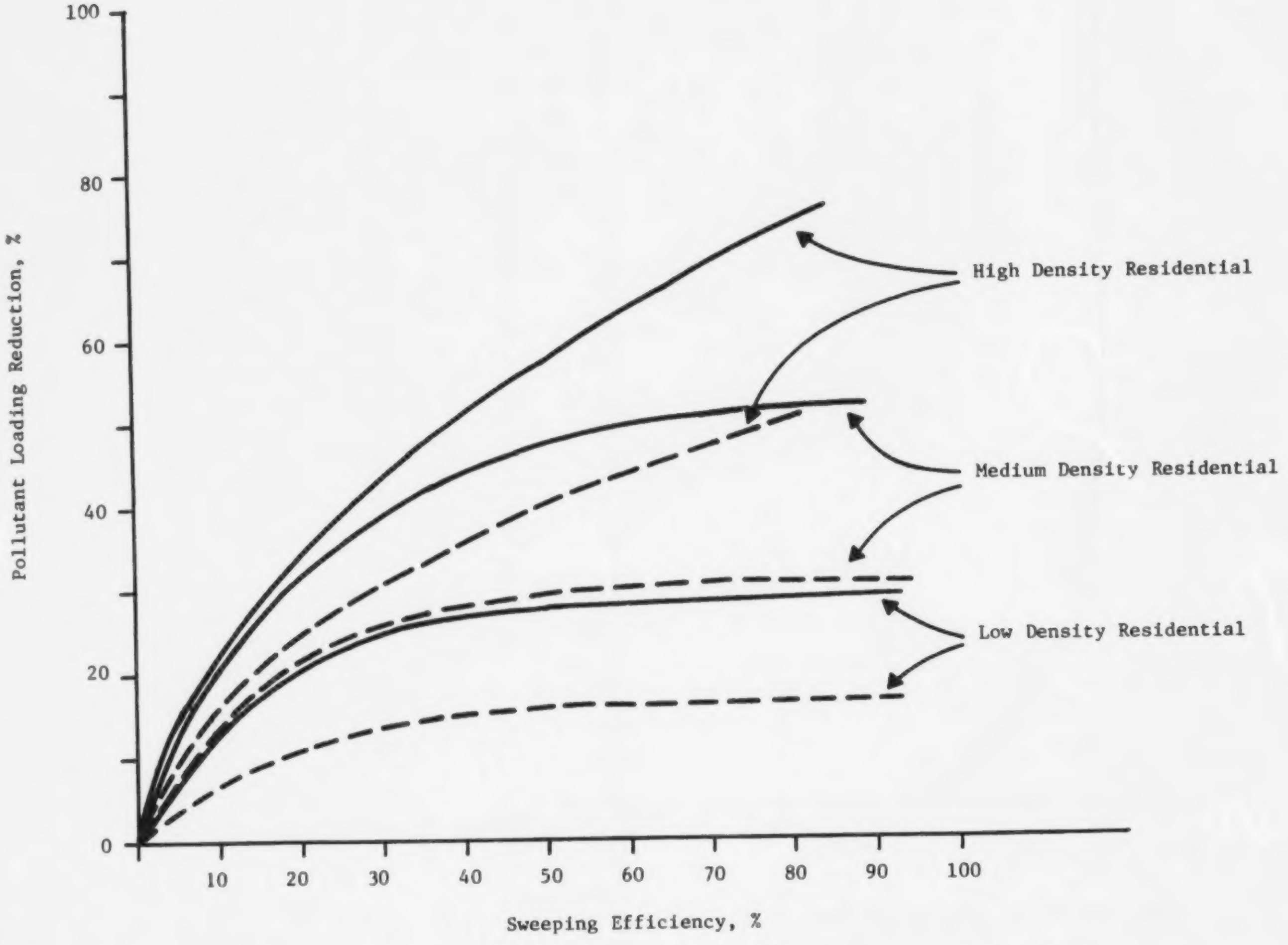

Fig. II-C-2. Effect of sweeping efficiency on pollutant loadings (sweeping interval = 7 days)

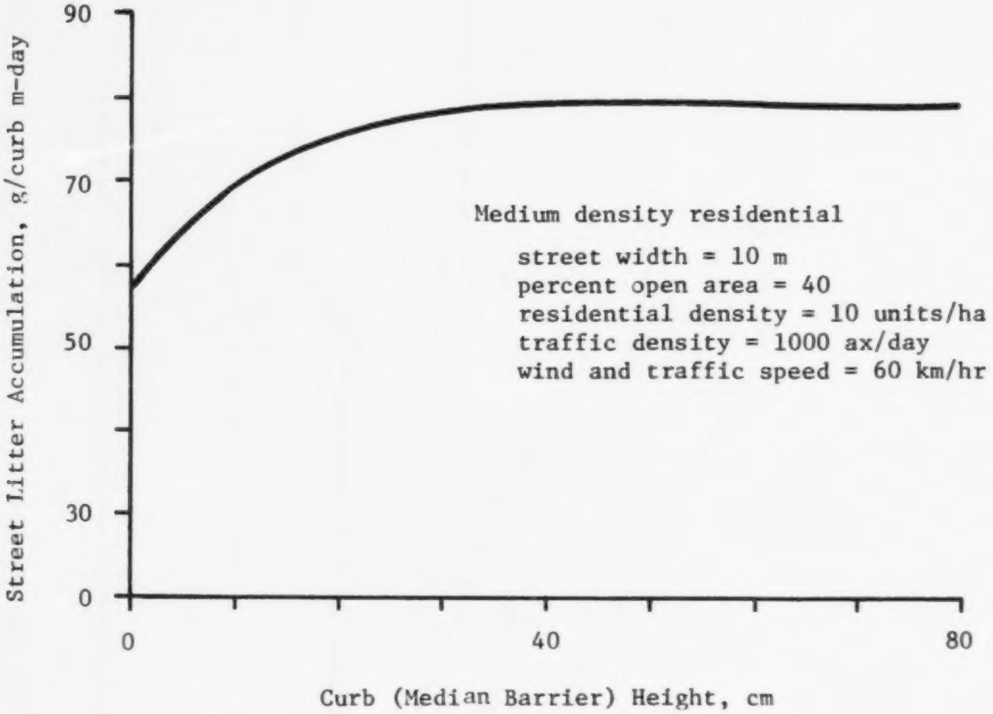

Fig. II-C-3. Effect of curb (median barrier) height on street litter accumulation.

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PART III

A SIMPLE, EMPIRICAL MODEL FOR PREDICTING RUNOFF QUALITY FROM SMALL WATERSHEDS

by

D. S. CHERKAUER

ABSTRACT

A simple model for calculating the time distribution of suspended solid loads in a runoff event is presented. Instantaneous solids concentrations are related to discharge per unit drainage area, rainfall intensity, antecedent dry period, and stage of urban development. A set of empirical curves developed from observations on small watersheds within the Menomonee and Milwaukee River watersheds allows calculation of suspended solids concentrations for any percentage of urbanization. These concentrations can then be combined with discharges predicted by some standard means to provide loading. The model has been tested in watersheds from a variety of climatic, geologic and topographic regions. For storms within the calibration limits of the model, it predicts loads with reasonable accuracy.

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III-1. INTRODUCTION

One of the objectives of the Menomonee River Pilot Watershed Project was to synthesize the collected data into a form useful to planners and others concerned with the effects of runoff quality from future urban development. Models, calibrated with data gathered from the Menomonee River Study can be extrapolated to project the effects of developemnt. The LANDRUN digital model represents the primary modeling effort and like most available digital runoff models for calibration, it requires detailed input of the hydraulics of the Watershed and its channels. When precise inputs can be provided, the model produces precise results. However, in many urban areas in the Great Lakes Watershed, either the necessary input data is not available or time and budget constraints do not allow development and/or calibration of a digital model.

With these concerns in mind, a methodology is presented for development of a simple empirical model for predicting runoff quality from small watersheds. This model is less precise than LANDRUN in its final product, but it is one which can be calibrated for a particular urban area with data which is easily obtainable.

III-2. CONCLUSIONS

Table III-1 summarizes the investigation and provides a comparison of the observed and predicted suspended solids loads for each event discussed. After calibration in an area, the model is able to predict suspended solids loads to about ± 20%. It cannot be used on watersheds (such as Underwood Creek) which are substantially larger than those used for calibration without introducing a substantial error (Table III-1). In addition, the model is valid only for the range of rainfall intensities and totals for which it is calibrated. It would probably be advisable to calibrate it locally for small, intermediate and large storms, but insufficient data has been analyzed to determine the value of multiple calibrations.

Extrapolation of the model to areas of vastly different climatic, geologic and topographic conditions produced surprisingly good results. Admittedly, predicted solids loads were generally substantially different from the observed ones (error range of 8 to 80%, Table III-1). However, within the constraints of its calibration, the model was always within the proper order of magnitude for watersheds and events that produced from 1,100 to 46,000 kg suspended solids/km^2. In addition, it cannot be determined from the published watershed descriptions the extent of active construction in these areas. Such construction is not accounted for in the model.

Two conclusions can be drawn from the apparent flexibility of this statistical model. First, the regression coefficients developed for the Menomonee River Watershed are valid for a wide range of conditions. Local calibrations should be made to refine the coefficients for local conditions. Secondly, it can be inferred that rainfall conditions (intensity and duration of antecedent dry conditions), amount of runoff and degree of urbanization are much more important in determining suspended solids in urban areas than are such local conditions as topography, geology and vegetation. If this were not the case, the regression information transferred from one area to another would bear no relationship with reality.

Furthermore, it has been suggested that the model produces reasonably accurate estimations of suspended solids loads after it has been calibrated for local conditions. The principal value of the model is the ease with which it can be calibrated. Runoff samples must be collected from a variety of small streams for which the following is known:

a. Intensity and quantity of rainfall capable of producing runoff.
b. antecedent rainfall conditions,
c. discharge at the time of sample collection, and
d. land usage information for the sampled watersheds.

Multiple regression relations are then developed for suspended solids concentrations and Items a. and c. for each stream. The regression coefficients are plotted as functions of urban development (Fig. III-1). The

Table III-1. **Comparisons of predictive capabilities of model for suspended solids loads**

Date or event no.	Drainage basin		Rainfall			Loads			Comments
	Area, km^2	Urban, %	Amount, cm	Intensity, cm/hr	Antecedent dry period, days	Observed, kg/km^2	Predicted, kg/km^2	Difference, %	
					Brown Deer, Milwaukee, Wisconsin				
6/8/77	7.5	65	1.3	0.25	3	2,900	2,290	-21	Meets all conditions of calibration
					Underwood, Milwaukee, Wisconsin				
4/23/76	49.7	54	5.4	0.30	1	2,100	850	-60	In calibration watershed but too large
					Third Fork, Durham, North Carolina				
27*	4.3	80	3.8	1.14	11	46,200	27,400	-41	Outside calibration area
29*			6.0	0.86	5	14,300	19,300	+35	
32*			2.0	0.48	2.5	3,800	3,500	+8	
					Bloody Run, Cincinnati, Ohio				
9/25/70	9.6	77	1.7	0.73	1	3,220	5,280	+64	Outside calibration area
10/20/70			2.3	0.45	6	2,800	5,000	+79	
					Baker Street, San Francisco, California				
11/5/69	0.73	100	1.6	0.33	19	1,130	6,765	+500	Outside calibration area
11/5/69			1.6	0.33	1**	1,130	1,730	+53	

*Taken from Colston (1).

**Antecedent dry period of 1 day was substituted for the 19 days.

suspended solids concentration model is then interfaced with whatever method is used locally to predict runoff quantities.

Relatively few samples are needed; only 15 to 20 from each of 5 to 8 watersheds as a minimum should be collected from a range of storm events. However, it is unnecessary to monitor the runoff events continuously. As long as discharge is known spot sampling is adequate because each sample is treated independently by the model. If continuous monitoring data is available, the precision of the model should be markedly enhanced by separate consideration of the rising and falling limbs of the hydrograph.

Location coding: BD - Brown Deer; BV - Beaver; DB - Donges Bay; HO - Honey;
NO - Noyes; SC - Schoonmaker; T - Trinity

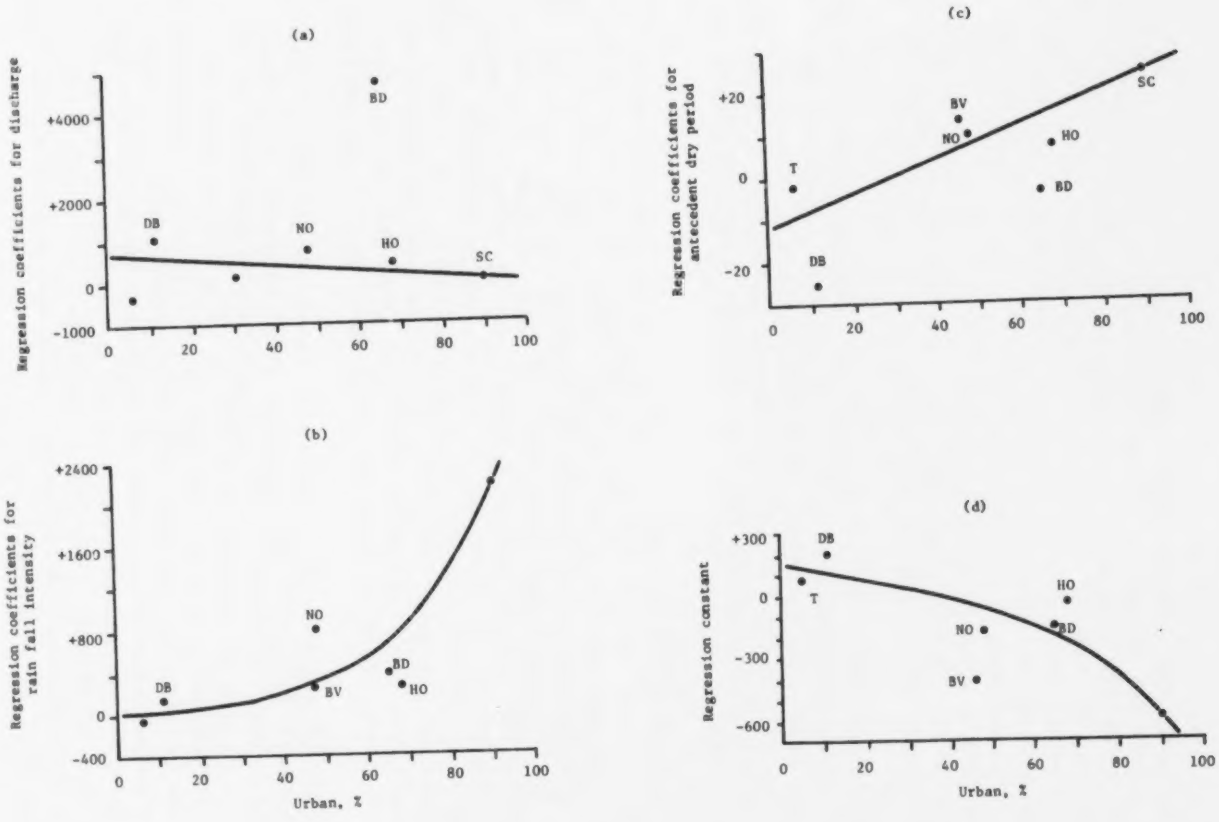

Fig. III-1. **Regression coefficients for model for total suspended solids.**

III-3. METHODS AND PROCEDURES

Efforts have been concentrated on small watersheds (<28 km^2) tributary to the Menomonee and Milwaukee Rivers. The watersheds are small enough to have simple hydraulic responses to precipitation events and these responses are amenable to the type of analysis proposed. Also, small streams are more dramatically affected by the processes of urbanization than larger receiving streams, because urban development will occupy a greater percentage of the watershed. Furthermore, concentration on small watersheds provides flexibility in the model, because larger watersheds can be modeled as the composites of the small ones. On the other hand, a model developed for large watersheds is not easily adapted to smaller watersheds.

The Menomonee River monitoring stations used for development of this model were Noyes, Schoonmaker and Honey Creeks and the Little Menomonee River at Donges Bay Road. In addition, three tributaries to the Milwaukee River, which are adjacent to the Little Menomonee at Donges Bay Road and Noyes Creek, were used (2,3). Water quality and flow in these watersheds were monitored manually from 1974 until 1977.

The initial step in the data analysis was to determine what independent factors most closely control the quality of water in surface runoff. Data were handled independently for each stream. Furthermore, analysis was restricted to rainfall runoff events and each sample for a particular stream was treated as an independent input and were all combined in a multiple regression analysis. A variety of rainfall and watershed parameters were tested as independent variables in the regression to determine whether they were statistically related to the dependent variable, i.e., the concentration of the chemical of interest. Only the procedure used in establishing and testing a model for total suspended solids is described here. However, similar development could be done for other water quality parameters.

With suspended solids concentration as dependent variable, total precipitation, rainfall intensity and duration, precipitation event recurrence interval, antecedent rainfall, instantaneous runoff/unit area of drainage, and temporal position of the sample within a runoff event were all tried as independent variables in a multiple regression analysis. Consistently, for the watersheds considered, the most important independent variables proved to be instantaneous runoff/unit area of drainage, rainfall intensity and antecedent rainfall conditions, in order of descending correlation. For comparison, the significant independent variables for total P concentration were total precipitation, instantaneous runoff and antecedent rainfall, again in descending order of importance.

It should also be pointed out that the position of the sample within the time framework of the runoff event may merit further attention. A relative time parameter was used, namely, a ratio of elapsed time since the start of runoff to an average response time for the watershed. Response time was defined as the time elapsed between the start of runoff and the crest of the hydrograph. As a result, samples on the rising limb had relative time ratios < 1.0, those on the descending limb were > 1.0. Separation of samples into rising and falling limb categories improves the statistical significance of the multiple regressions. However, this separation has not been included in the model because it may reduce the availability of data for calibration at other sites.

After the initial determination of primary independent variables, multiple regressions were run in each watershed. The regression coefficients for each independent variable were plotted as a function of the extent of the watershed which was urbanized (Fig. III-1). The extent of urbanization is the sum of residential, commercial, industrial and transportation land uses. This factor was used--rather than extent of imperviousness--because it is more readily obtainable from literature or from local or regional planning agencies.

The graphs in Fig. III-1 can be used to create a multiple regression equation for a small watershed for which degree of urbanization is known. Table III-2 lists equations for several levels of urban development. Thus a user need know only the following to operate the model:

a. Watershed drainage area (km^2),
b. area urbanized (%),
c. instantaneous discharge for the time suspended solids concentration is desired (m^3/sec),
d. rainfall intensity (cm/hr), and
e. antecedent rainfall period, i.e., number of days since preceding rain which produced runoff rain (days).

The degree of urbanization determines which equation to use (Table III-2; Fig. III-1), and the equation provides the instantaneous suspended solids concentration after Items a, c, d and e are entered in the model. The instantaneous discharge values can be obtained from any runoff predicting system available to the user, from the basic "Rational Method" to the more sophisticated digital models. Any error inherent in discharge prediction will be additive in this water quality model.

However, a word of caution is essential for developing the suspended solids model. It has been found that the regression coefficient for instantaneous discharge is sensitive to active construction. For those watersheds where construction is underway (Brown Deer) coefficients are produced which fall above the line in Fig. III-1a. Data were insufficient to determine the extent to which construction activity affects the coefficient, but it is known that the model will produce erroneous results under such conditions.

Table III-2. Coefficients for final regression equations for various degrees of urbanization*

Watershed urbanized, %	Coefficient for QA, $m^3/sec/km^2$ (a)	Coefficient for I, cm/hr (b)	Coefficient for A, days (c)	Regression constant (d)
0	+700	0	-12	+160
20	+550	+80	-3.5	+80
40	+400	+200	-4.5	0
60	+250	+520	+12.5	-120
80	+100	+1420	+21	-400
100	-50	+3000	+29	-820

*$SS = a(QA) + b(I) + c(A) + d$, where SS is suspended solids concentration (mg/L), QA is discharge/unit drainage area ($m^3/sec/km^2$), I is rainfall intensity (cm/hr), A is antecedent dry period (days).

III-4. RESULTS AND DISCUSSION

In an attempt to determine the reliability of the model and limitations of its use, several tests have been tried. The model has been used to predict suspended solids loads for streams in the study area, one of which was used in calibrating the model. Also, it was tested against published data for small watersheds outside the Great Lakes Watershed. It would have been desirable to also test in the Great Lakes area outside of southeastern Wisconsin, but data for small watersheds were not available. The model also was tested on watersheds having different geological and hydraulic conditions from those used to calibrate it and for storms of different magnitudes and intensities from the studied storms.

For each test, measured flow rather than predicted flow was used because the model provides no method of flow prediction, and the use of any runoff predictor introduces an error in the final load calculations. That error compounds with any error due to the suspended solids prediction. Separation of these two errors is difficult and clouds the validity of the test of the empirical model. Thus, it is assumed that each user will interface the suspended solids model with his own method of obtaining flow.

Comparison of observed suspended solids loads with those predicted by the model for the Brown Deer Watershed for a storm event on 6/8/77 is shown in Fig. III-2. The Watershed is one used for calibration of the model, but data from this event were not used in the calibration. The Watershed is 65% urbanized and the equation derived from Fig. III-1 is:

$$SS = 200\ QA + 680I + 14.5A - 170,$$

where

SS is suspended solids concentration (mg/L)
QA is discharge/unit area ($m^3/sec/km^2$)
I is rainfall intensity (cm/hr)
A is antecedent dry period (days)

The agreement is obviously good. The comparative suspended solids loads/unit area (QA x SS) are shown in Fig. III-3, and agreement again is good. All further tests compare loads because they are more reliable indicators of average stream conditions during an event. Concentrations tend to fluctuate dramatically in the early and late stages of an event when discharge is very low. However, these fluctuations are of little importance because the stream does not carry large quantities of suspended solids at these times. Comparison of loads attaches more importance to the bulk of the sediment transported.

A second test (Fig. III-4) was run on Underwood Creek, one of the larger (49.7 km^2) tributaries to the Menomonee River. In this case, agreement is poor likely because the Watershed is outside the size range of watersheds for which the model was calibrated. Because of its size, Underwood Creek is not simply a single stream with ephemeral tributaries, but has two main branches which complicate its hydraulics. The model does not work well on complex or large stream systems.

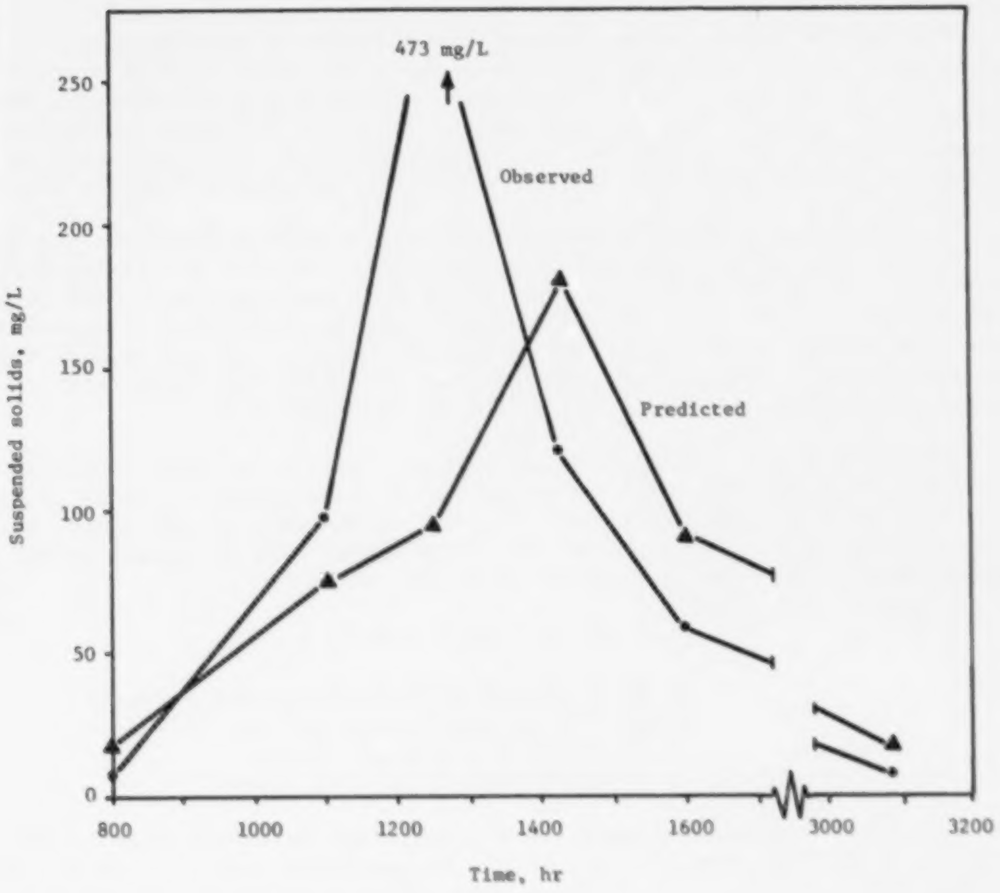

Fig. III-2. Comparison of observed and predicted suspended solids concentrations for Brown Deer Creek on 6/8/77. Total precipitation was 1.32 cm, the antecedent dry period was 3 days and rain fall intensity was 0.25 cm/hr.

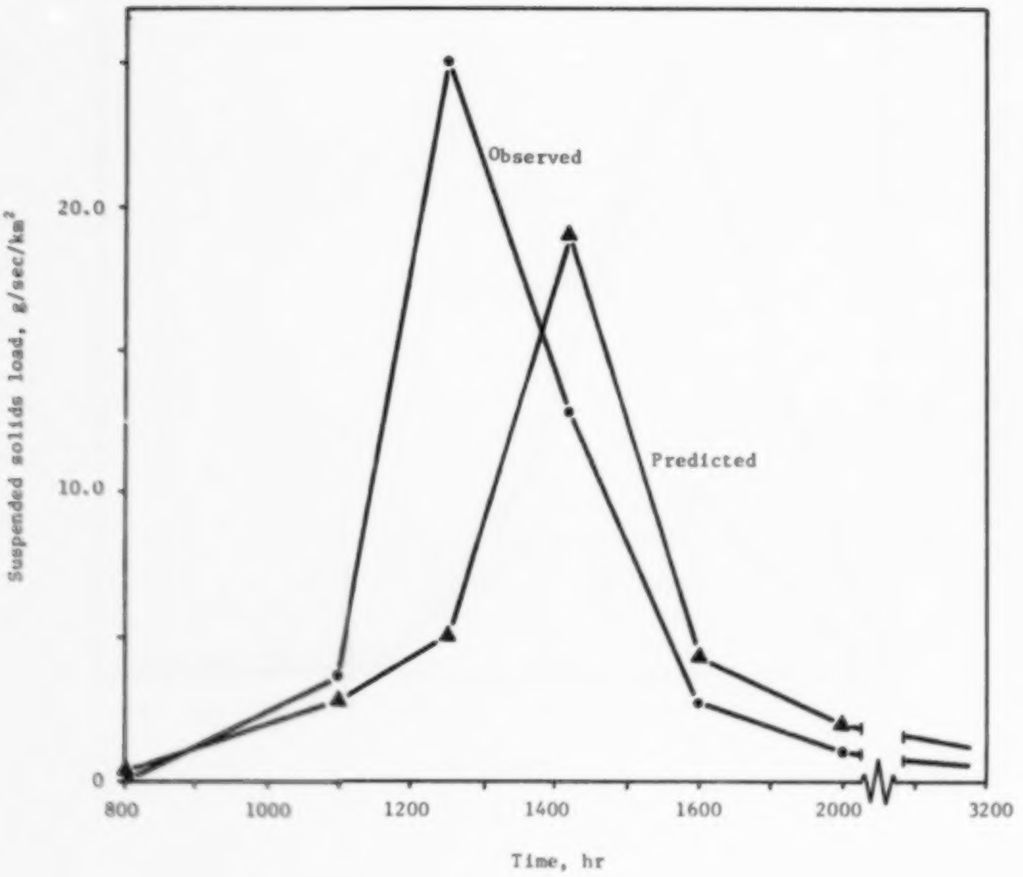

Fig. III-3. Comparison of observed and predicted suspended solids loads for Brown Deer Creek, Milwaukee, Wisconsin on 6/8/77. Total precipitation was 1.32 cm, antecedent dry period was 3 days and rainfall intensity was 0.25 cm/hr.

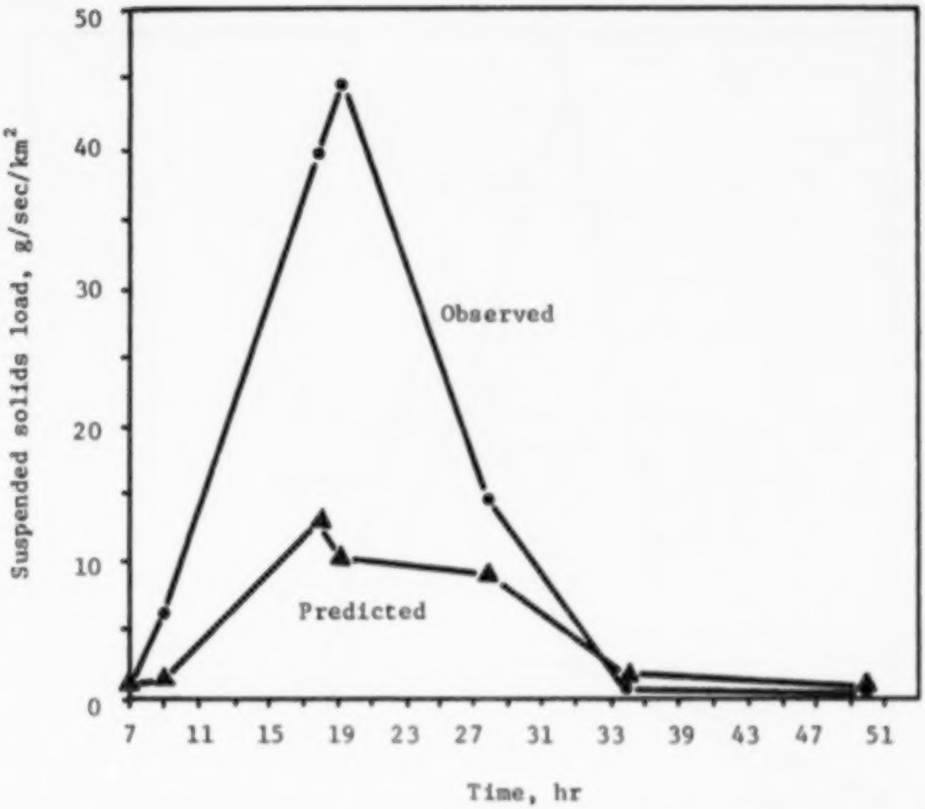

Fig. III-4. Comparison of observed and predicted suspended solids loads for Underwood Creek on 4/23/76. Total precipitation is 5.4 cm, antecedent dry period was 1 day and rainfall intensity was 0.30 cm/hr.

Other tests were run using data from Durham, North Carolina (1), San Francisco, California (4) and Cincinnati, Ohio (5). The purpose of these tests was to determine whether the coefficients established in Wisconson could be transferred to other urban areas where topographic, climatic and geologic conditions were different. It was anticipated that these conditions would each play major roles in defining the coefficients and consequently the degree of transferability that could be achieved.

The Durham, North Carolina data is most complete, providing runoff and suspended solids for a wide range of rainfall events on a 4.3 km^2 watershed which is 80% urban. The terrain is steeper than that in Milwaukee (average land slope of 6 to 7% in Durham, 2% in Milwaukee) and geologic conditions are entirely different. However, for storms which fall within the range of intensity and total precipitation of storms used to calibrate the model, there is remarkably good agreement (Figs. III-5 to III-7).

The model was calibrated in the Menomonee River Watershed using storms which had intensities > 0.25 cm/hr and total precipitation > 1.0 cm. With the Durham data, the model was used to predict suspended solids for each of the 34 events for which rainfall data was available (1). It was found that the model did not agree with observed data for events of intensity < 0.25 cm/hr (19 events). Of the remaining 15 events, 7 had precipitation of < 1.0 cm, and were not handled well by the model. However, for the 8 events which had intensity > 0.25 cm/hr and total precipitation > 1.0 cm, the model worked well (Figs. III-5 to III-7). It seems that rainfall conditions and percentage development may play a larger role in controlling the sediment regression coefficients than local topography and geology.

Data from the Bloody Run Watershed in Cincinnati (5) also provided an opportunity for investigating the transferability of the model. This Watershed is 9.63 km^2 in size, is 80% urban and has an average slope of about 5%. Again it is topographically and geologically different from the Menomonee Watershed. Data for several events are published, but only four fall within the total precipitation and intensity range valid for the model. Use of the model to predict suspended solids loads for Bloody Run, Cincinnati are shown in Figs. III-8 and III-9. Agreement with observed values is not particularly good. The results for the 9/25/70 event (Fig. III-8) reveal a major shortcoming of the model, i.e., the model is extremely insensitive to changes in suspended solids during events when discharge remains relatively constant. The Bloody Run flow response to a rainfall of 1.65 cm (intensity of 0.73 cm/hr) on 9/25/70, varied only from 0.27 $m^3/sec/km^2$ to 0.30 $m^3/sec/km^2$ over a 3.5 hr period. Consequently, the model, which is discharge dependent, predicted a relatively constant solids load while observed values were variable. Such a response from an urban watershed is probably anomalous, but nonetheless, the model does not handle it well.

The San Francisco data (4) provides a less comprehensive test than Durham or Cincinnati. Only one storm fits in the intensity and total rainfall conditions for the model, and it has an anomalous antecedent dry period of 19 days. For a watershed of 0.73 km^2 which is 100% developed, the model greatly overpredicted suspended solids (Fig. III-10). However, it does properly predict for this Watershed the unusual conditions where suspended solids concentrations increase when runoff decreases (Fig. III-11). This dilution effect is anomalous for suspended solids. In fact, if an antecedent

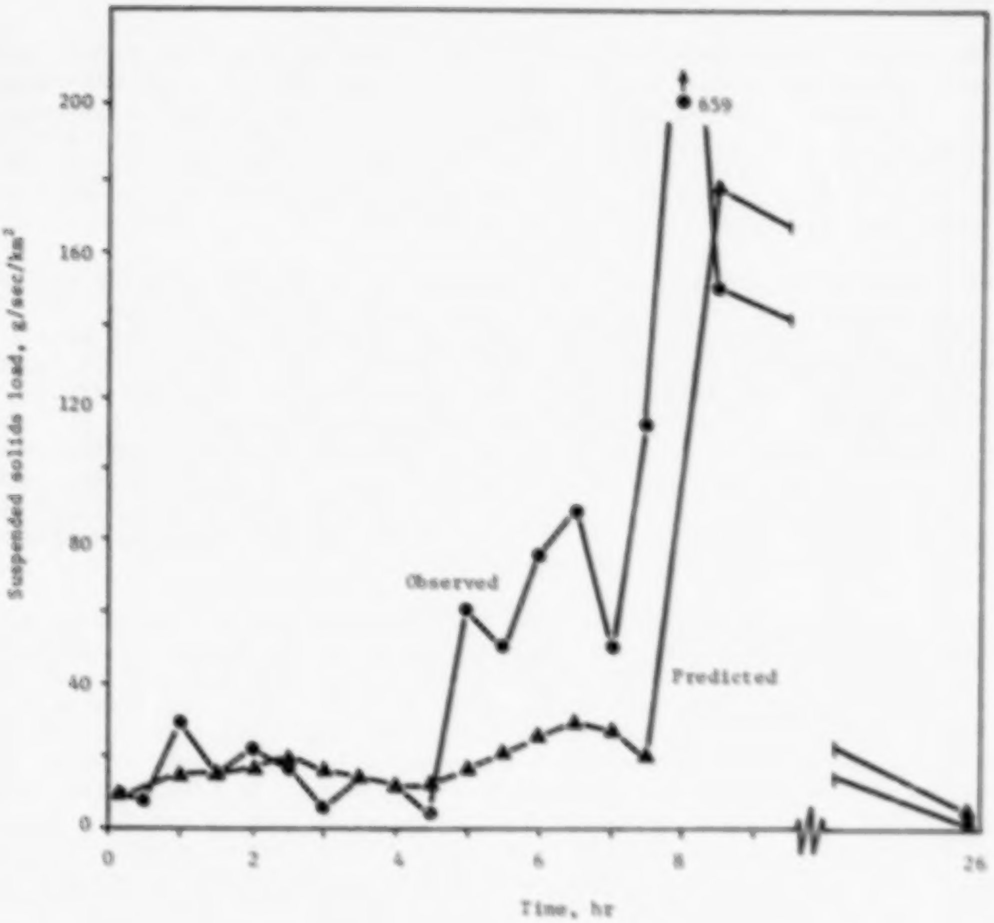

Fig. III-5. Comparison of observed and predicted suspended solids loads for Event 32 at Third Fork Creek, Durham, North Carolina. Total precipitation was 2 cm, the antecedent dry period was 2.5 days and rainfall intensity was 0.48 cm/hr.

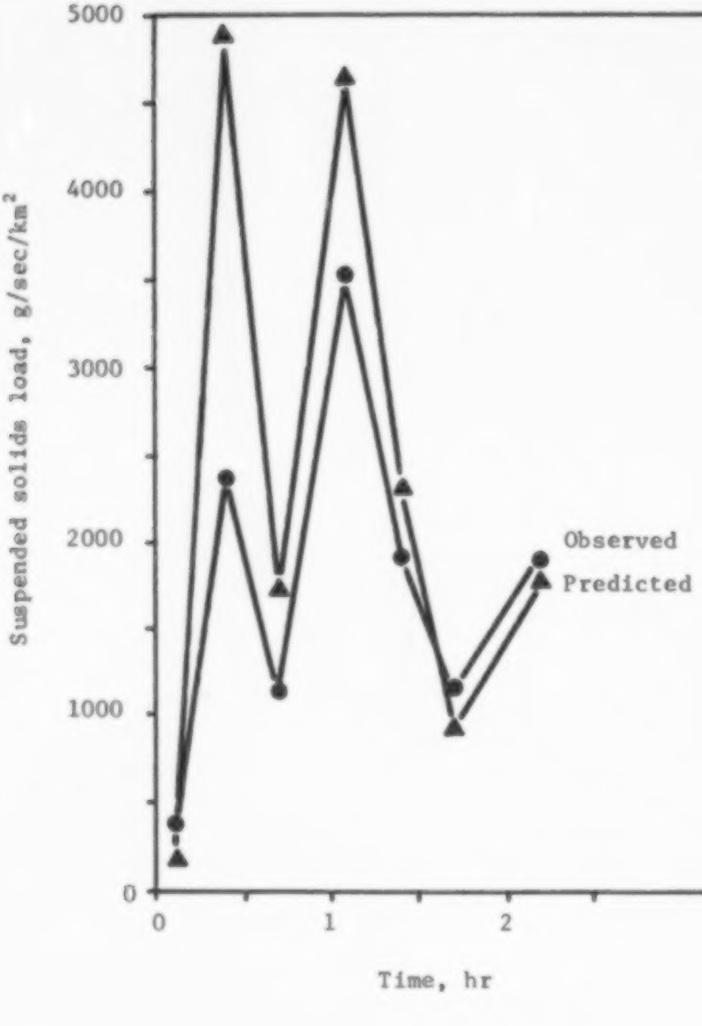

Fig. III-6. Comparison of observed and predicted suspended solids loads for Event 29, at Third Fork Creek, Durham, North Carolina. Total precipitation was 6 cm, the antecedent dry period was 5 days and rainfall intensity was 0.86 cm/hr.

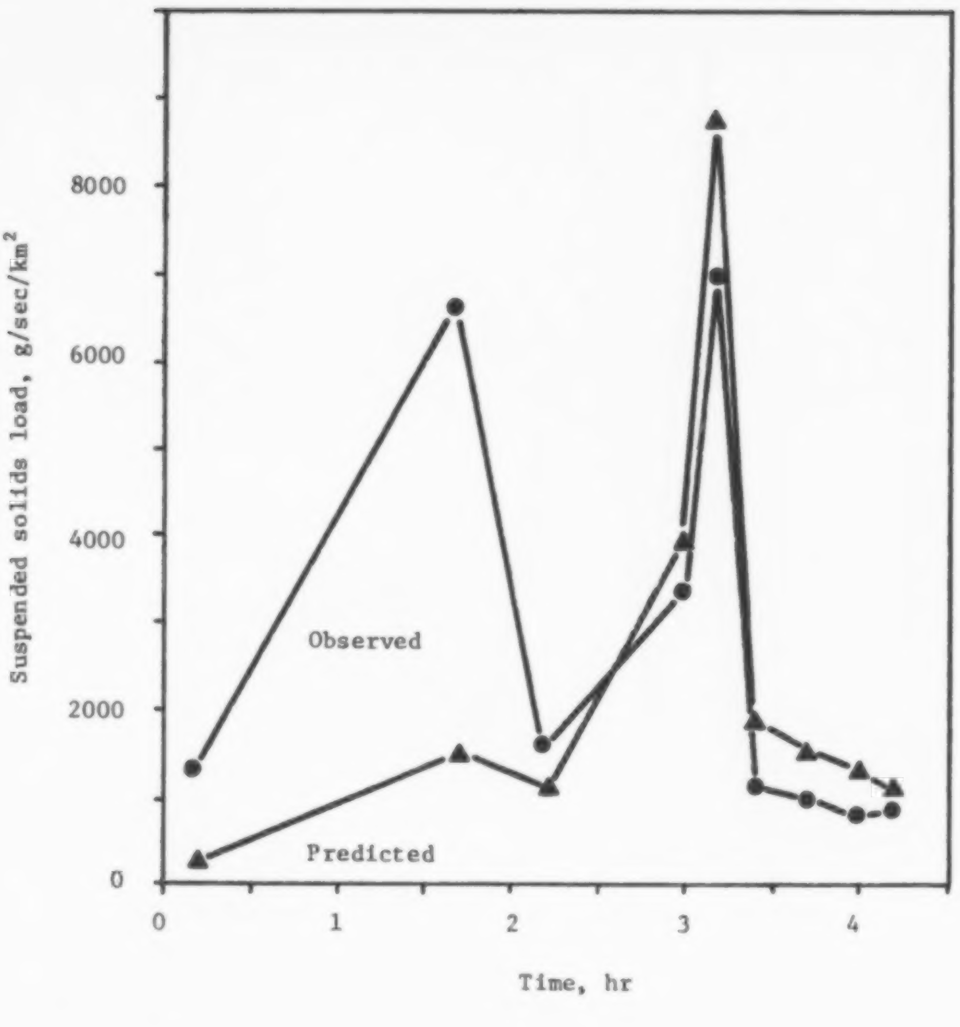

Fig. III-7. Comparison of observed and predicted suspended solids loads for Event 27 at Third Fork Creek, Durham, North Carolina. Total precipitation was 3.8 cm, the antecedent dry period was 11.3 days and rainfall intensity was 1.14 cm/hr.

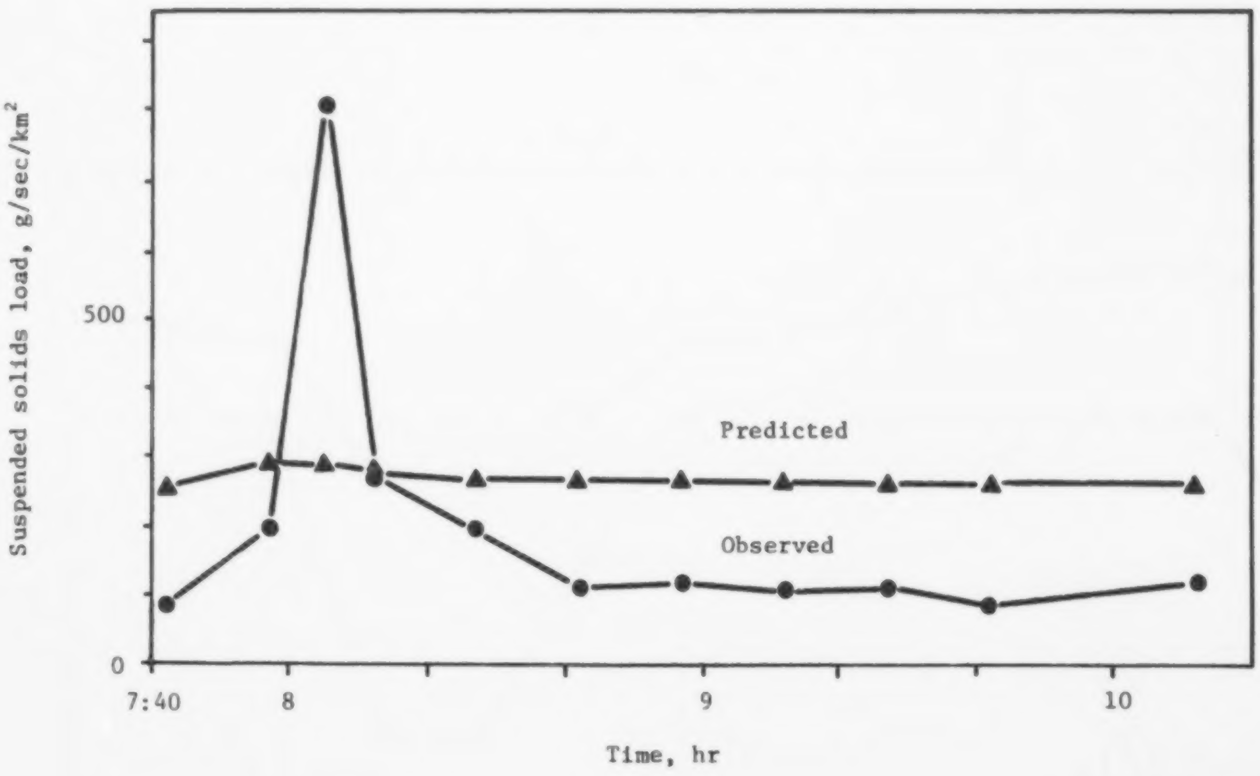

Fig. III-8. Comparison of observed and predicted suspended solids loads for Bloody Run, Cincinnati, Ohio on 9/25/70. Total precipitation was 1.7 cm, antecedent dry period was 1 day and rainfall intensity was 0.73 cm/hr.

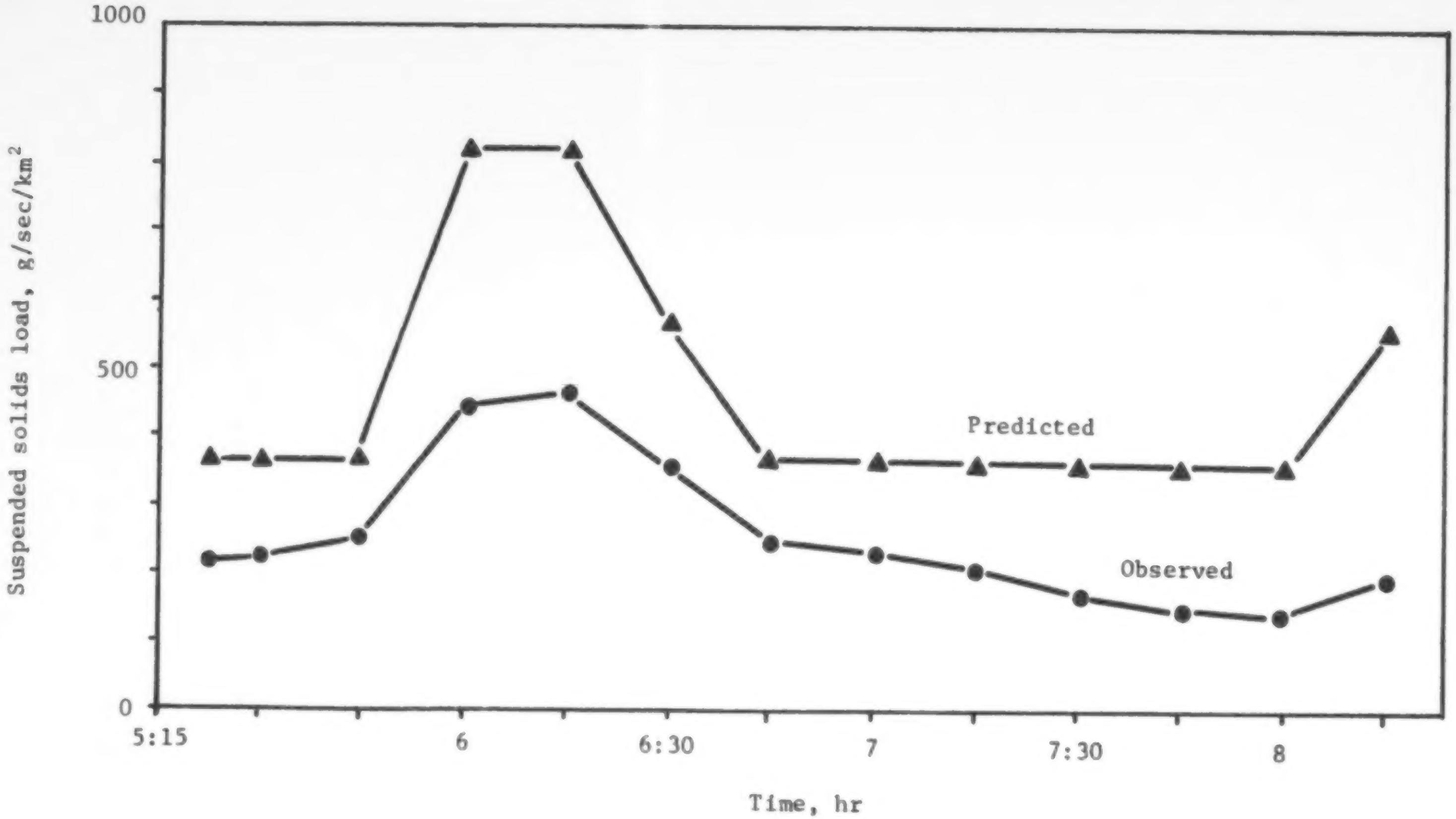

Fig. III-9. Comparison of observed and predicted suspended solids loads for Bloody Run, Cincinnati, Ohio on 10/20/70. Total precipitation was 2.3 cm, antecedent dry period was 6 days and rainfall intensity was 0.45 cm/hr.

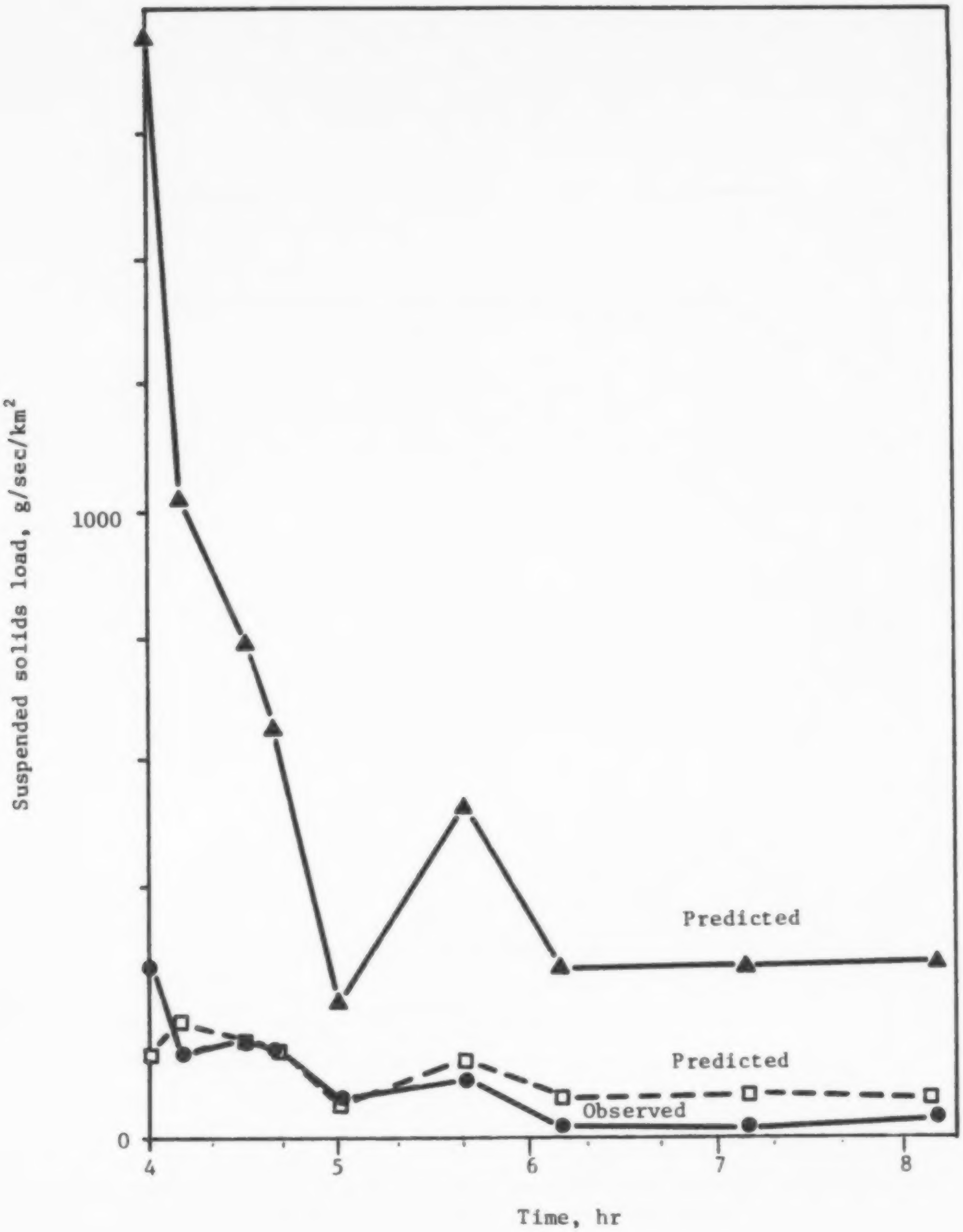

Fig. III-10. Comparison of observed and predicted suspended solids loads, Baker Street Basin, San Francisco, California on 11/5/69. Loads have been predicted using the general model (x) and also a modified model which reduces the importance of antecedent conditions (o). Total precipitation was 1.6 cm, antecedent dry period was 19 days and rainfall intensity was 0.33 cm/hr.

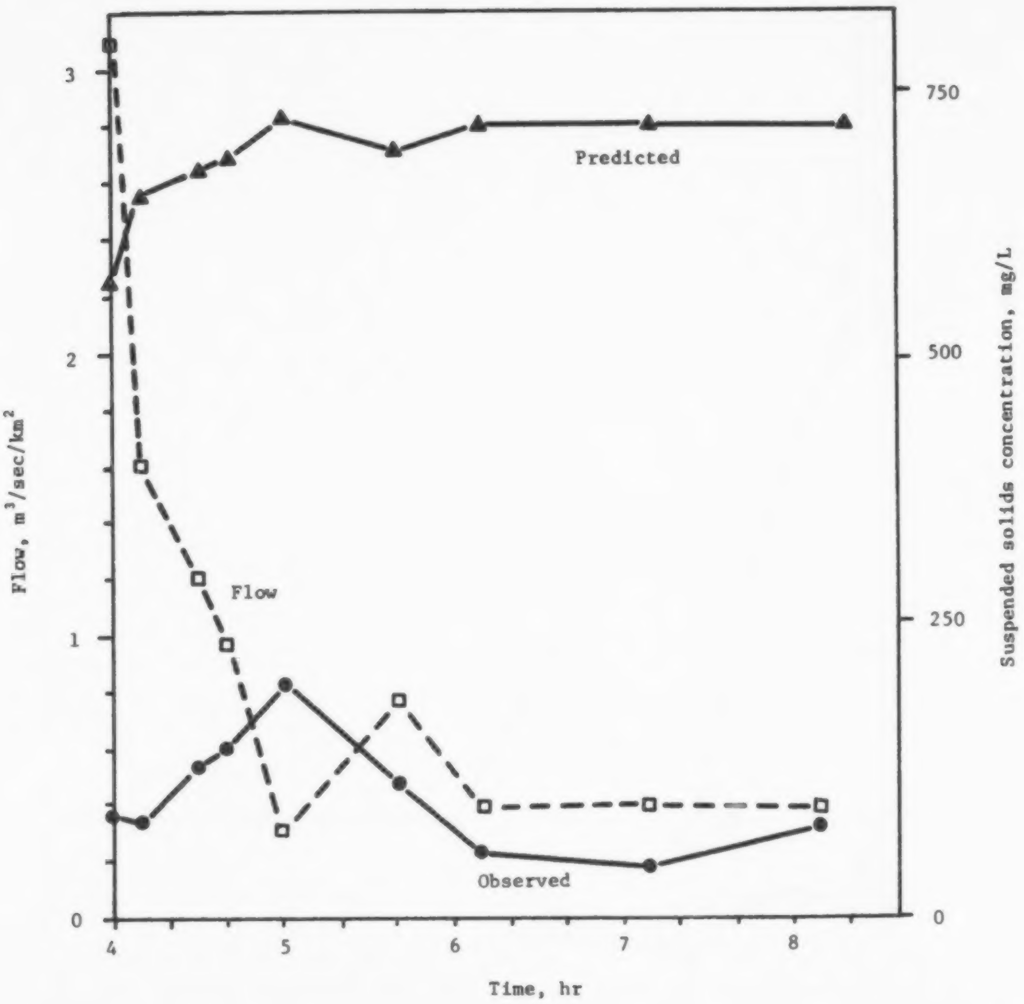

Fig. III-11. Comparison of observed and predicted suspended solids concentrations and flow for Baker Street Basin, San Francisco, California. Total rainfall was 1.6 cm, antecedent dry period was 19 days and rainfall intensity was 0.33 cm/hr.

dry period of 1 day is entered into the equation, the model produces very reasonable results. Exactly what this means is not understood. Perhaps the model does not work for such a steep (average slope 8 to 10%) watershed or for such long antecedent dry periods. Or perhaps on steep watersheds, the antecedent dry conditions become unimportant or the model is unaffected after 1 or 2 days. The interpretation of the test remains unresolved.

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